Update on the Validation of TES L2 Data Products

Greg Osterman & the TES Validation Team

TES Aura Validation Working Group Meeting

October 1, 2007

Jet Propulsion Laboratory
California Institute of Technology

Acknowledgements

- TES Validation Team
  - Kevin Bowman, Karen Cady-Pereira, Tony Clough, Annmarie Eldering, Brendan Fisher, Robert Herman, Daniel Jacob, Line Jourdain, Susan Kulawik, Michael Lampel, Qinbin Li, Jennifer Logan, Ming Luo, Inna Megretskaia, Ray Nassar, Gregory Osterman, Susan Paradise, Vivienne Payne, Hank Revercomb, Nigel Richards, Mark Shephard, Dave Tobin, Solene Turquety, Felicia Vilnrotter, Helen Worden, John Worden, Lin Zhang
- DIAL Lidar, FASTOZ, DACOM, Argus, ALIAS teams
- Aircraft teams and support staff, Ozonesonde investigators and coordinators, MOPITT, OMI, MLS, AIRS, WAVES teams

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TES Version 3 Data

- The Version 3 TES data includes:
  - Limb profiles valid into the upper troposphere
  - Improvements to the temperature retrieval due to updated CO2 spectroscopy from AER
  - Improvements to the methane retrievals
  - Species dependent quality control information
  - Use of GMAO GEOS-5 products in L2 retrievals
  - F04_04 in filename
- TES Version 3 data products began processing January 2007
- Complete reprocessing complete ~Nov 2007
- TES data and documentation can be found:
  - Langley Atmospheric Science Data Center eosweb.larc.nasa.gov
  - Aura Validation Data Center avdc.gsfc.nasa.gov

TES Version 2 Data

- The Version 3 TES data includes:
  - Limb profiles valid in the stratosphere
  - Methane and limb retrievals are of
  - Species dependent quality control information
  - Use of GMAO GEOS-4 products in L2 retrievals
  - F03_03 in filename
  - O3, CO, H2O, HDO, TATM , SST validated with known biases
- Completely processed (Sep 2004 – Dec 31, 2006)

TES Validation Status (Oct 2007) for Version 3 Data

Species	Validation Status
Nadir Ozone	Validated Stage 2
Nadir Carbon Monoxide	Validated Stage 2
Nadir Water	Validated Stage 2
Nadir Temperature	Validated Stage 2
Sea Surface Temperature	Validated Stage 2
Land Surface Temperature/Emissivity	Provisionally Validated
Nadir Methane	Provisionally Validated
Nadir HDO	Validated Stage 1 *
Limb Nitric Acid	Provisionally Validated
Limb Ozone	Provisionally Validated
Limb Temperature	Provisionally Validated
Limb Water	Beta (Validation Ongoing)

Validation Status Definitions

Term	Definition
Beta	Early release products for users to gain familiarity with data formats and parameters.
Provisional	Limited comparisons with independent sources have been made and obvious artifacts fixed.
Validated Stage 1	Uncertainties are estimated from independent measurements at selected locations and times. ** TES L2 retrievals include fully characterized error estimates **
Validated Stage 2	Uncertainties are estimated from more widely distributed independent measurements.
Validated Stage 3	Uncertainties are estimated from independent measurements representing global conditions.

TES Validation Papers

Primarily using TES v002 data

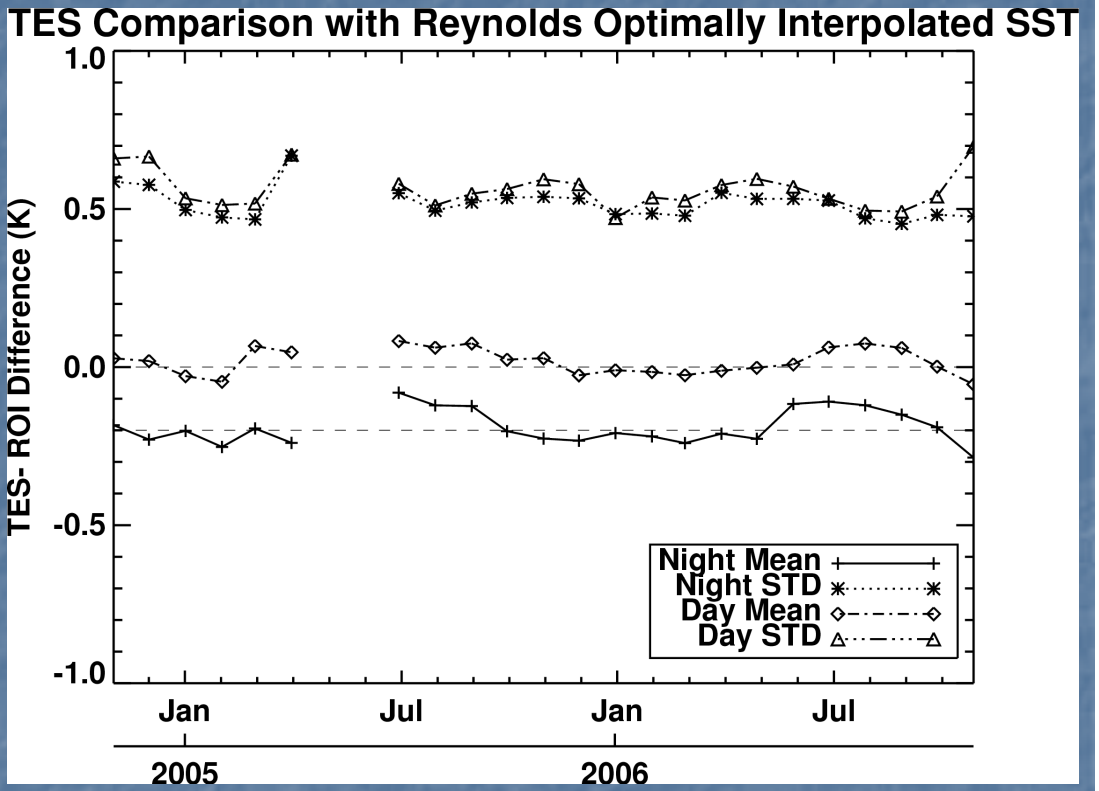
- M Shephard – L1B Radiances
- R Nassar – Nadir Ozone (Ozonesondes)
- N Richards – Nadir Ozone (Lidar/*in situ*)
- G Osterman – Nadir Ozone (Strat/Column)
- M Luo – Carbon Monoxide (DACOM)
- J Lopez – Carbon Monoxide (Argus/ALIAS)
- M Shephard – Water Vapor (sondes)
- R Herman – Atmospheric Temperature (sondes, aircraft)
- D Tremblay – Water Surface Temperature
- A Eldering – Clouds
- M Coffey (2) – Ozone, HNO3 (NCAR FTS)
- M Schoeberl – Tropospheric Ozone Column

TES Validation Report for V003 Data Products

- Available on TES websites – Oct 15, 2007
  - Pending JPL Document Review
- First time for sections on limb products and methane
- Analysis of V003 nadir products
- TES Validation Report focusing on V002 data products available since December 2006

TES L1B Radiance Validation

- Comparisons with Scanning-HIS
  - Agreement better than 0.3 K for BT 290-295 K
  - Agreement better than 0.5 K for BT 265-270 K
- Comparison with AIRS (Aqua) shows agreement to better than 0.5 K
- TES optical bench warm up in December 2005 gave 4-fold increase in signal to noise ratio at higher frequencies (Important for CO)
- TES sea surface temperature comparisons to Reynolds Optimally Interpolated product demonstrate radiometric stability



M Shephard et al., 2007

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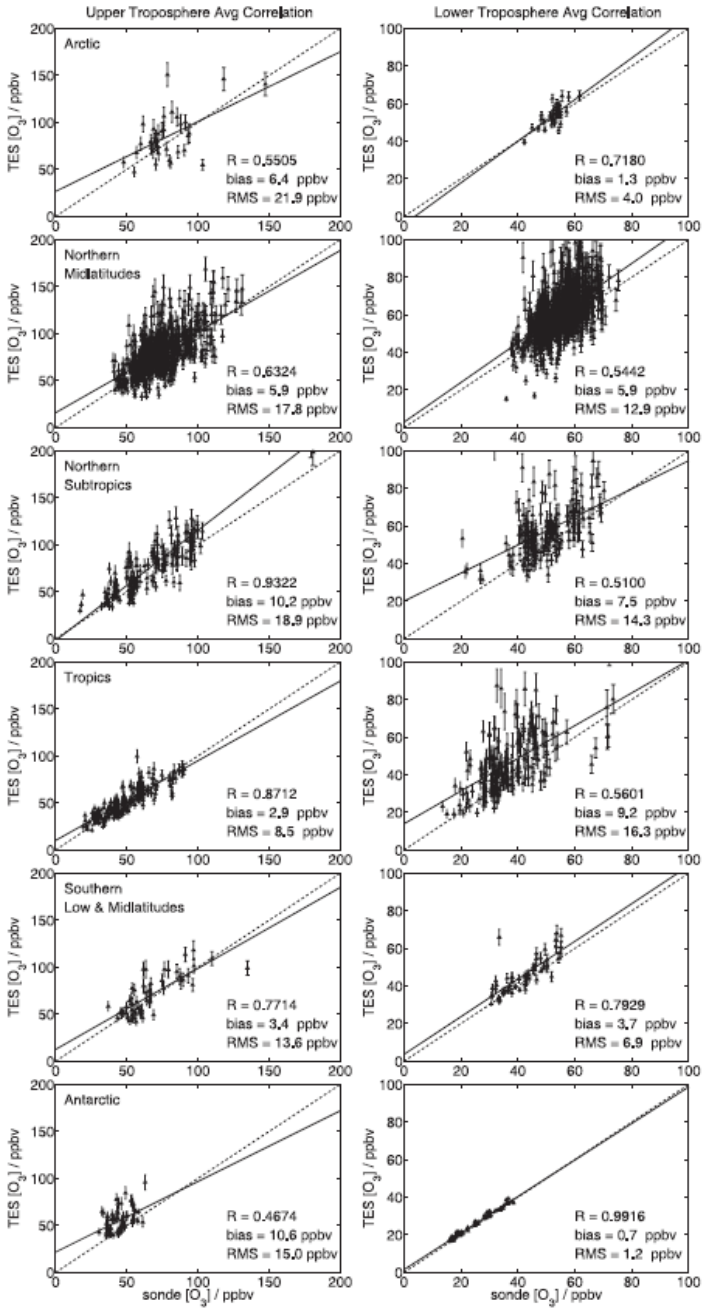
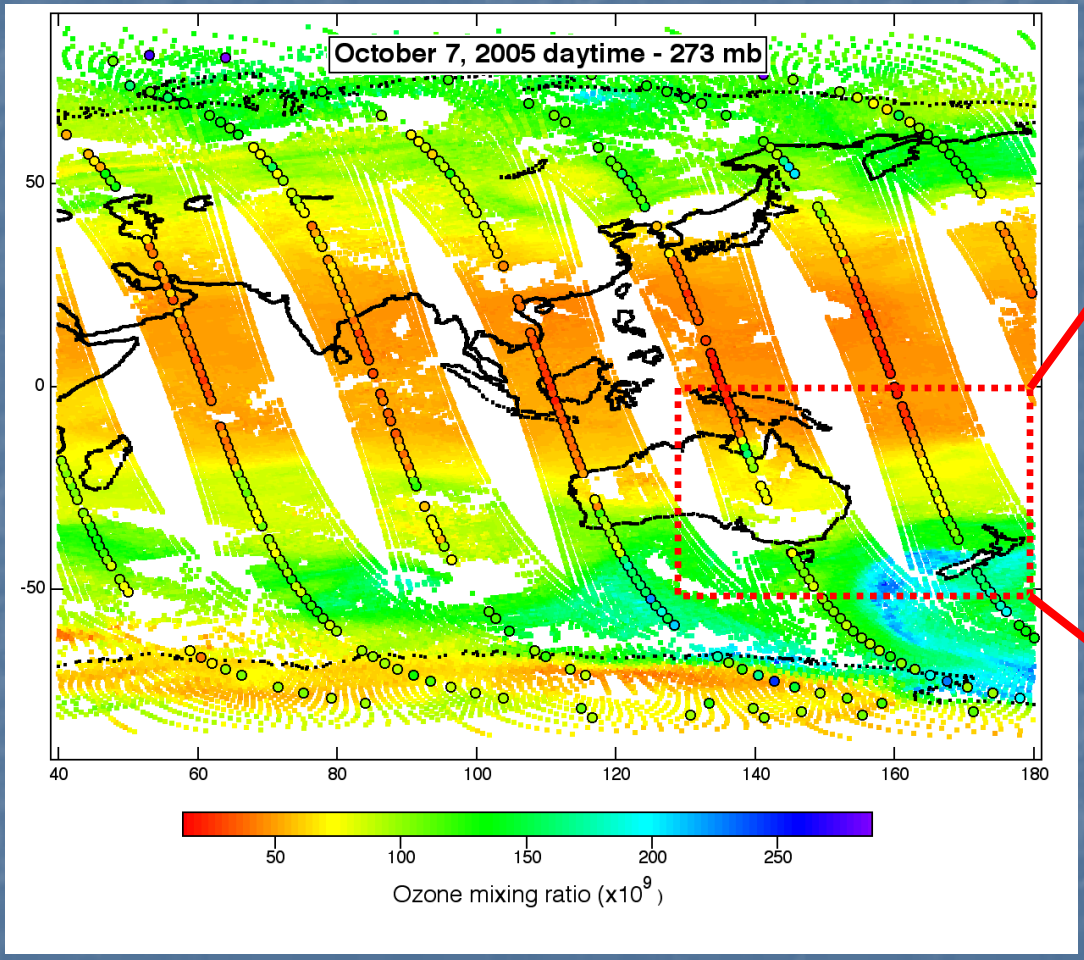
TES Nadir Ozone Validation

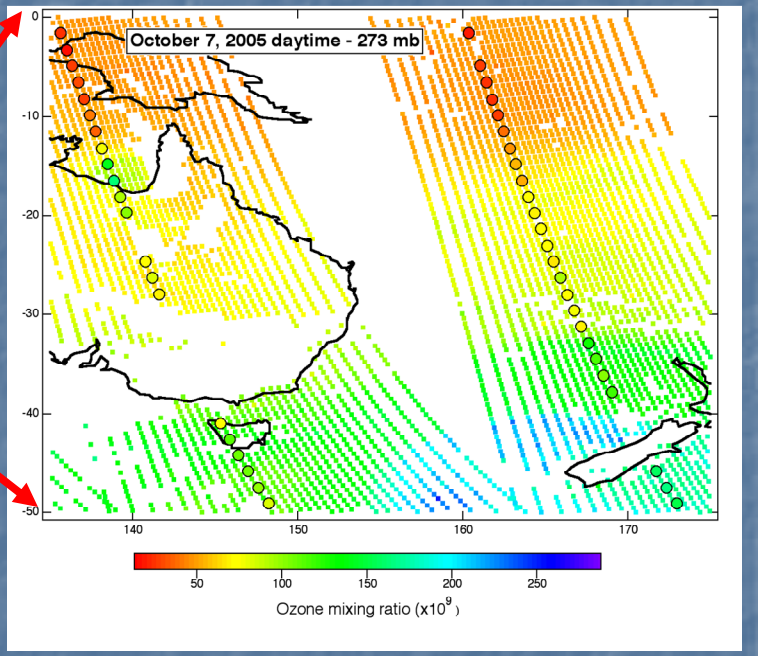
- Seasonal/Latitudinal statistics with ozonesonde comparisons
- High bias of 3-10 ppbv (sondes)
- High bias of ~7 ppbv (DIAL Lidar)
- Stratospheric column ~3 DU high compared with MLS
- Total column ~10 DU high compared with OMI
- Atmospheric variability affects the observed differences
- Relative variations in ozone measured by TES meaningful
- Analyses primarily using V002 data

R Nassar et al., 2007
N Richards et al., 2007
G Osterman et al., 2007



AIRS and TES Ozone at 273 mb - Oct 7, 2005





B Irion – AIRS Trace Gas Talk – Wed 1:30 PM

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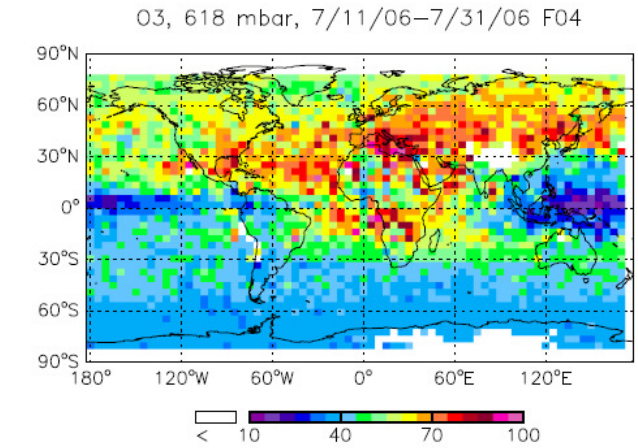
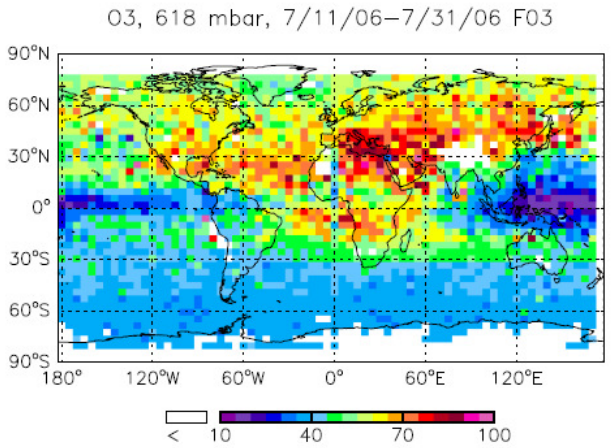
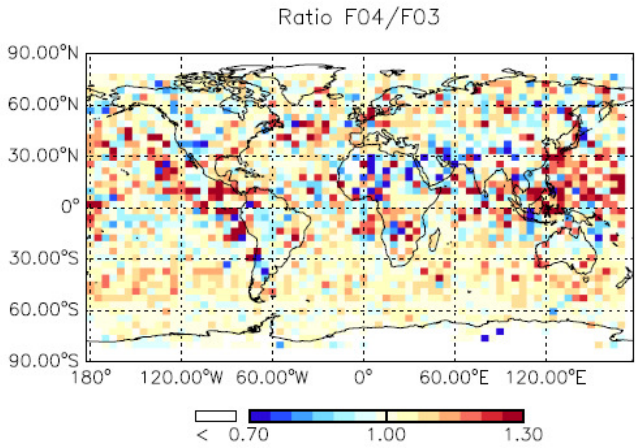
V2 – V3 Ozone Comparison







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J Logan, R Nassar & I Megretskaia

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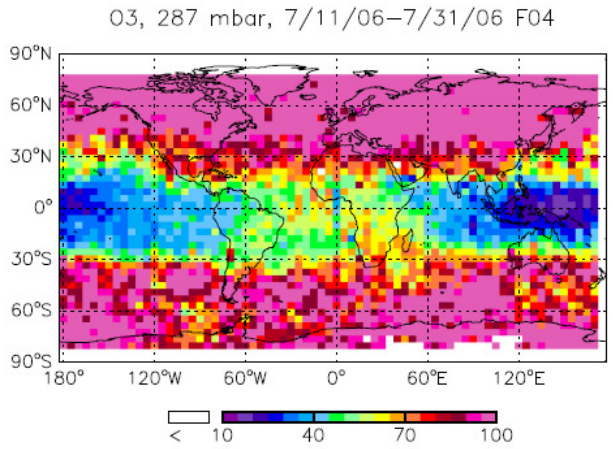
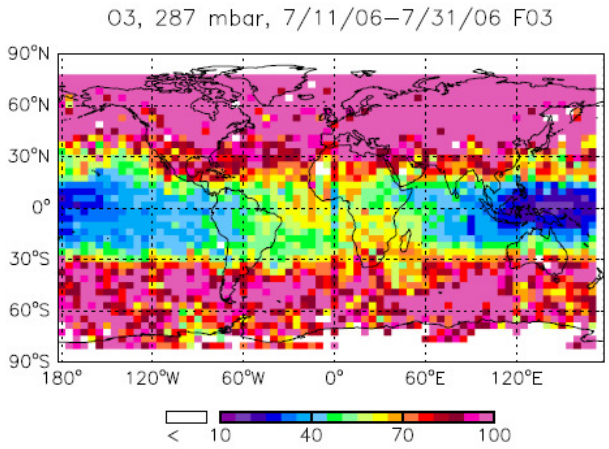
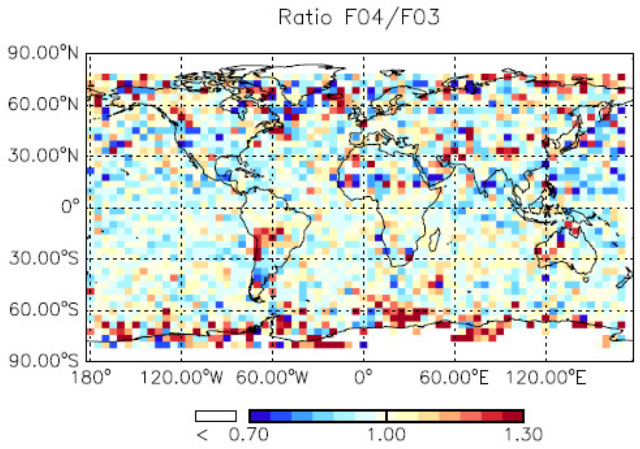
V2 – V3 Ozone Comparison



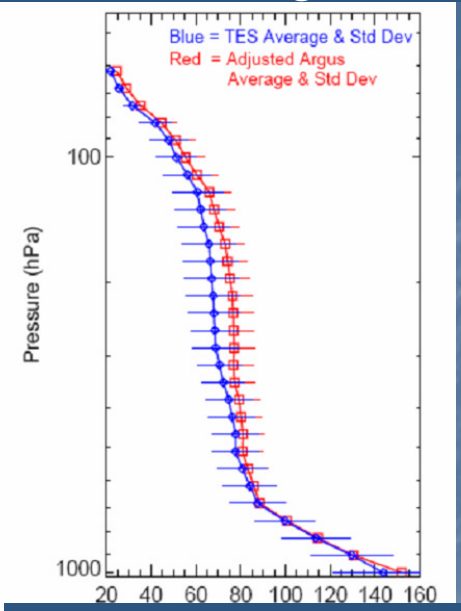




- Comparisons with DIAL Lidar for INTEX-B look slightly different when repeated with TES V003
- Comparisons with OMI total column ozone and MLS stratospheric ozone using V003 are consistent with V002 results

J Logan, R Nassar & I Megretskaia

AVE-Houston: Oct 2004
TES - Argus



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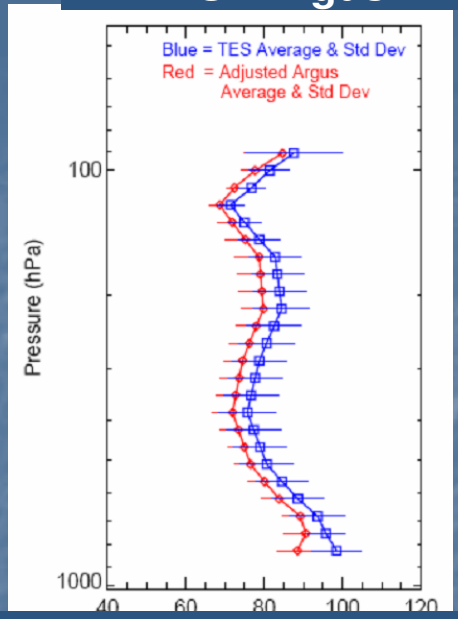
TES - Argus



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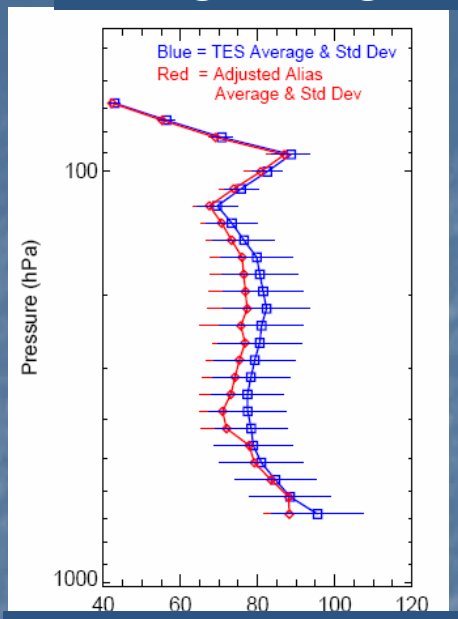
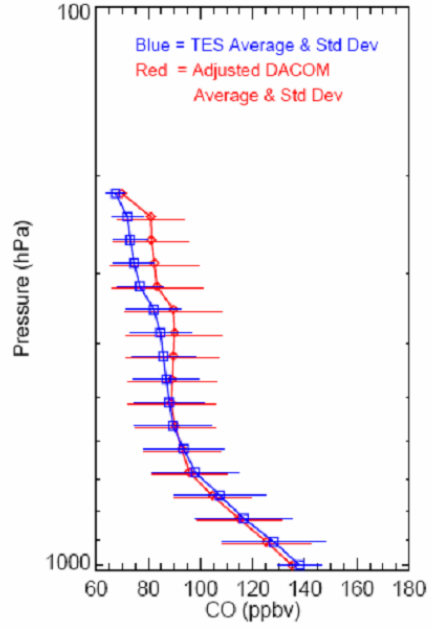
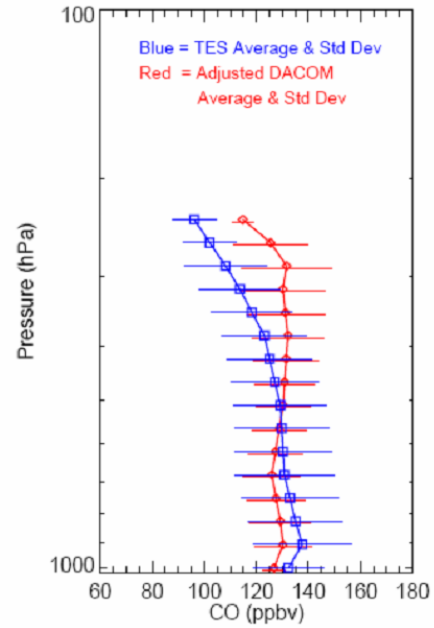
TES - ALIAS



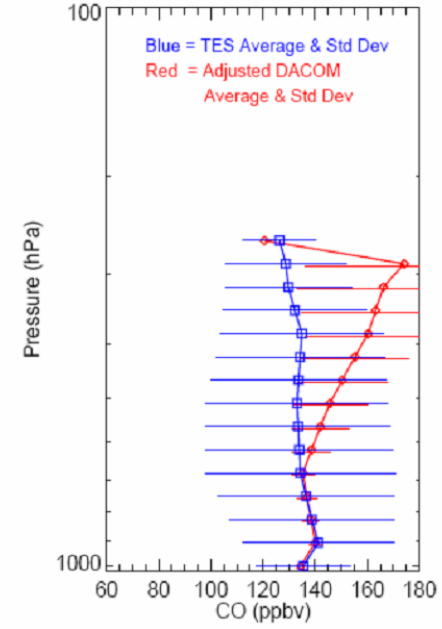
INTEXB-Houston: Mar 06
TES - DACOM



INTEXB-Hawaii: Apr 06
TES - DACOM



INTEXB-Anch: May 06
TES - DACOM



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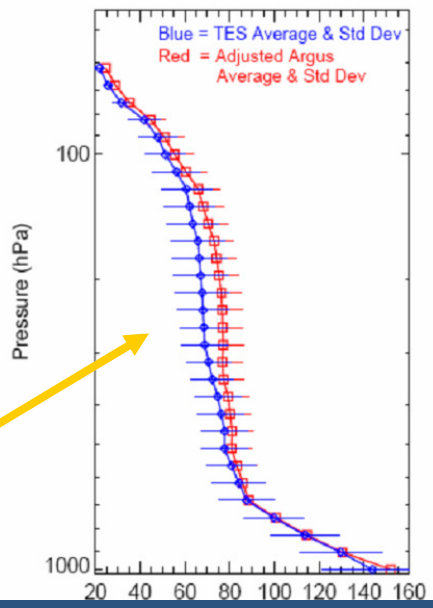
TES - Argus



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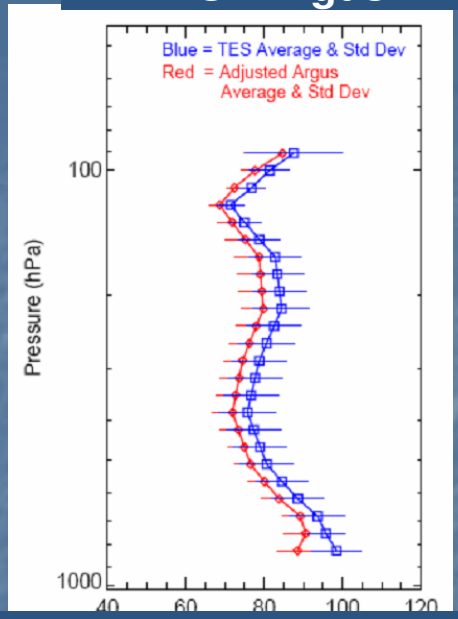

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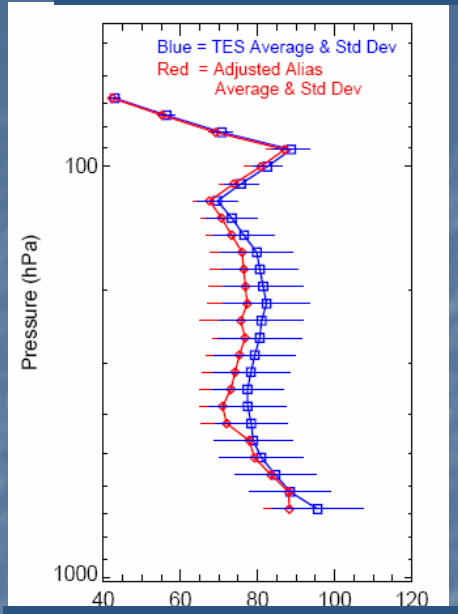

CO near Houston: TES < in-situ mid trop ~ 10%

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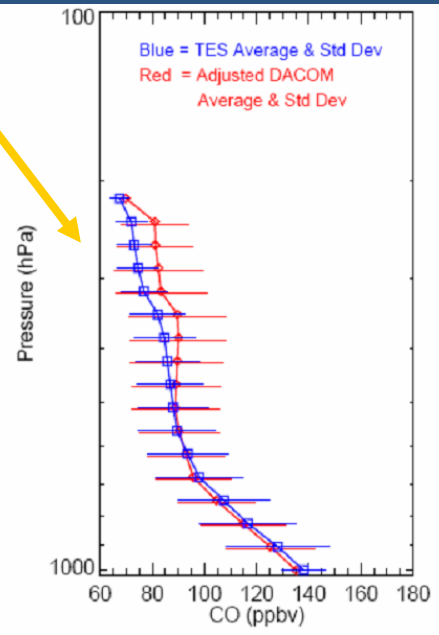

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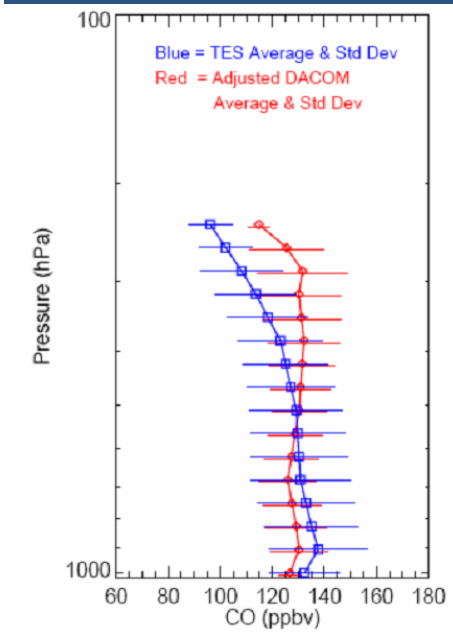

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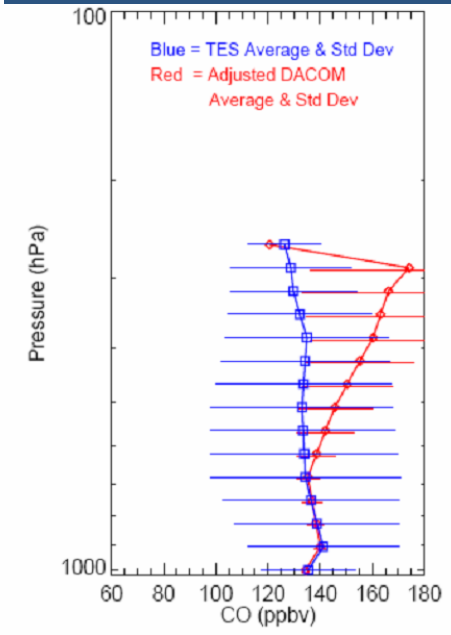

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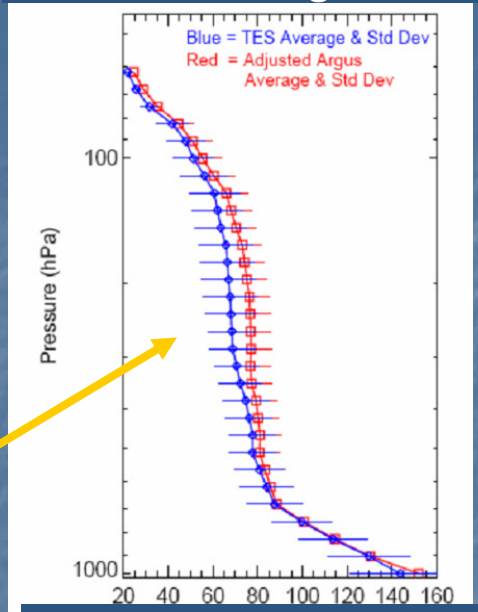

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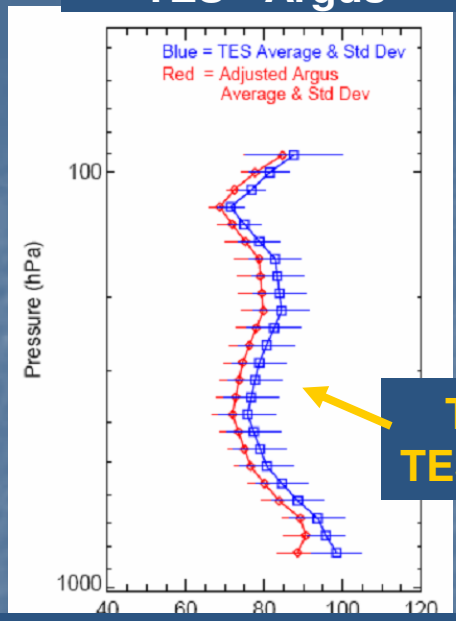

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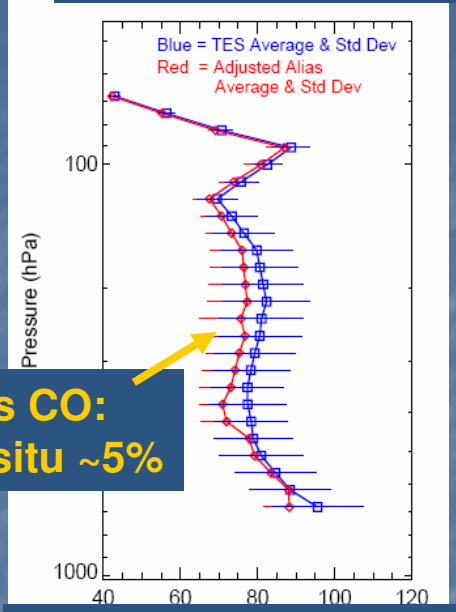

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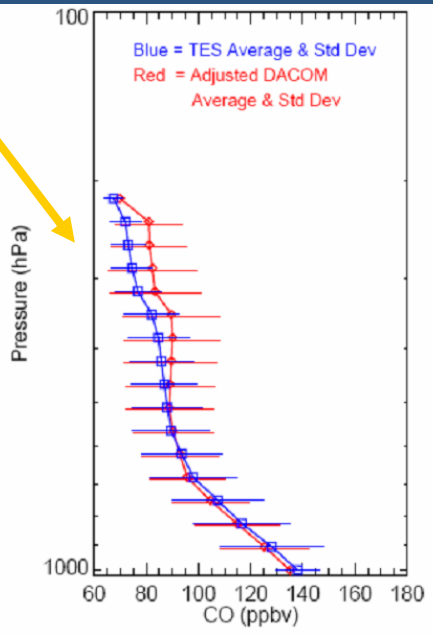

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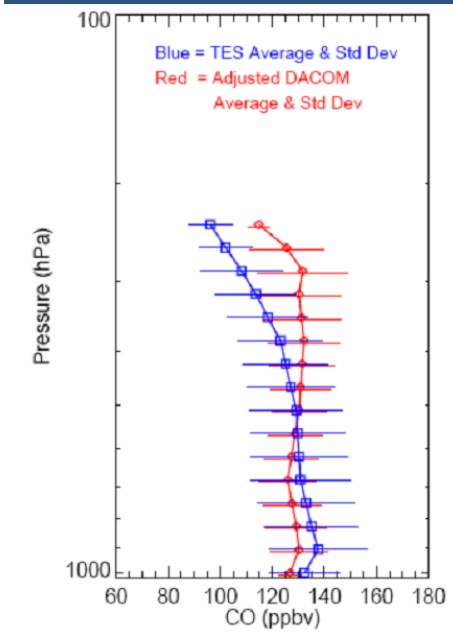

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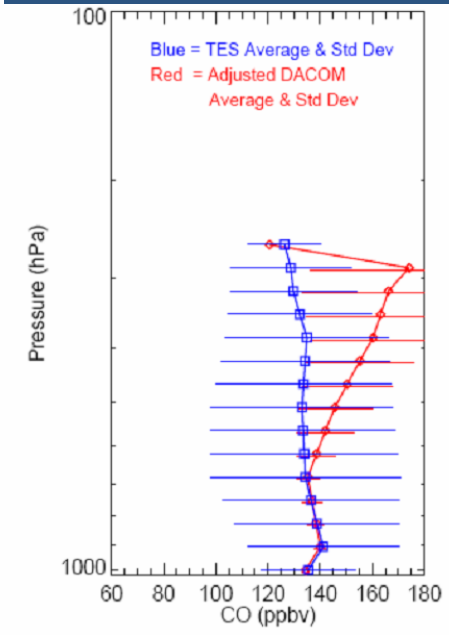

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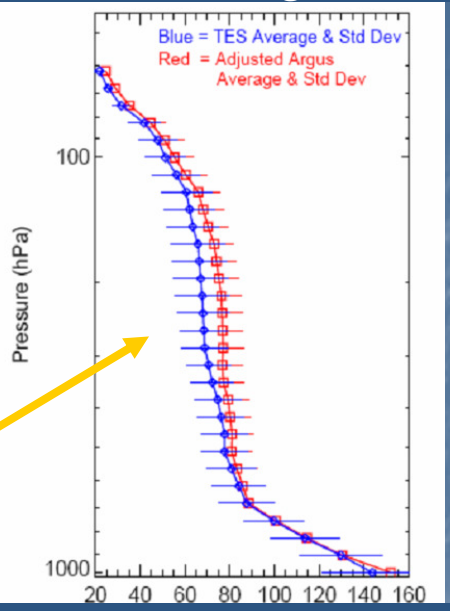

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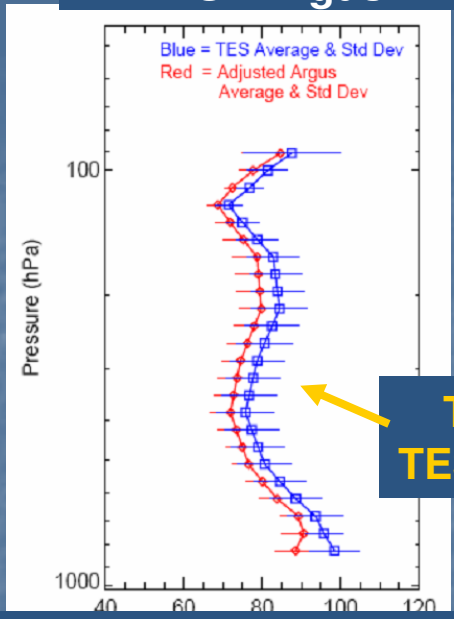

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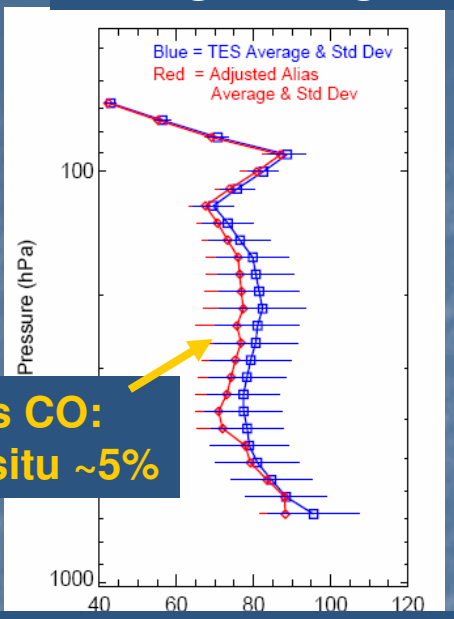

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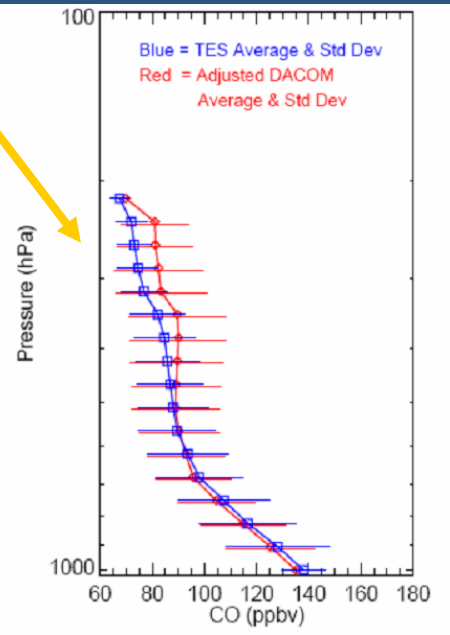

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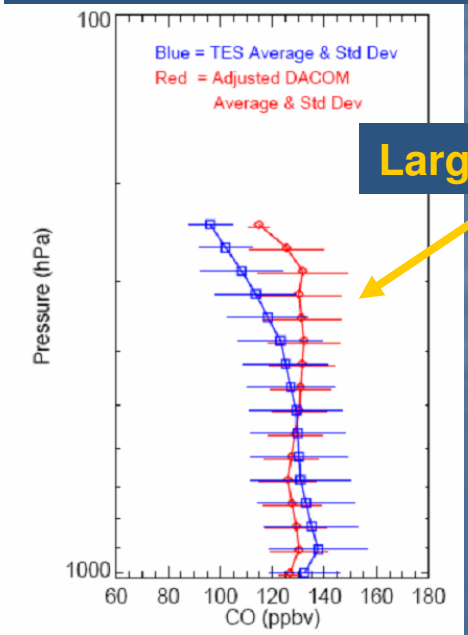

INTEXB-Anch: May 06
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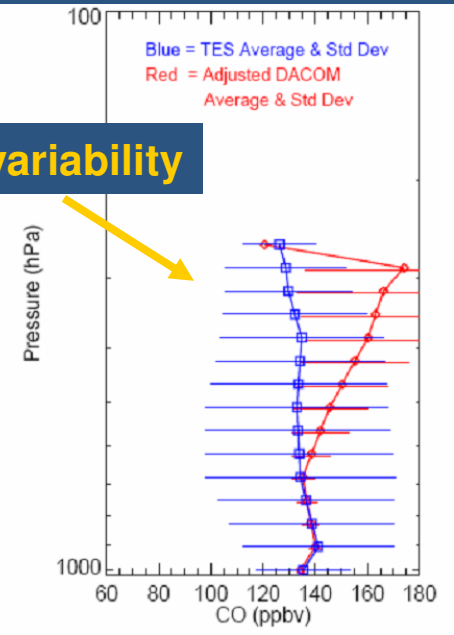
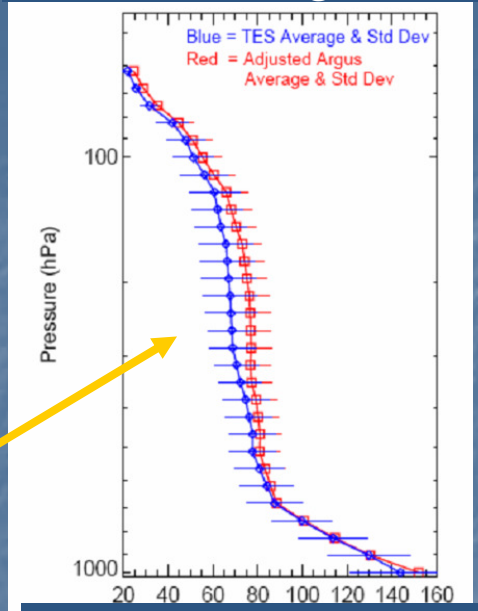
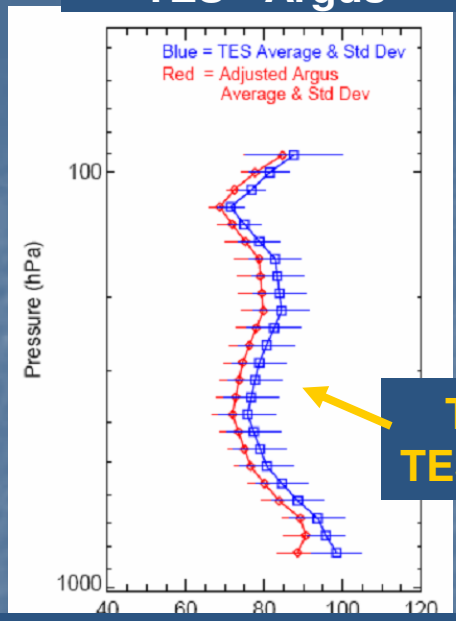


Large CO variability

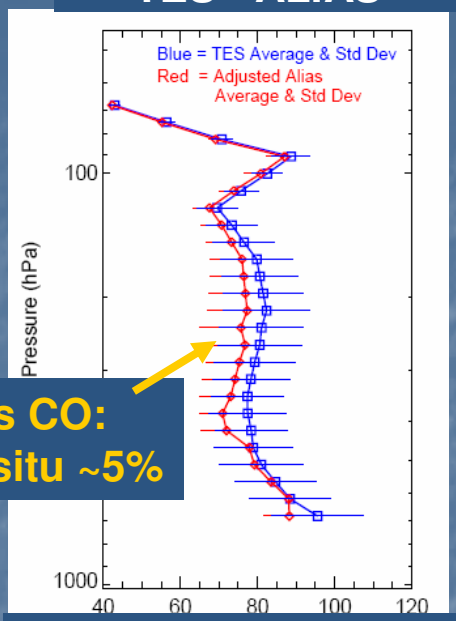
AVE-Houston: Oct 2004 TES - Argus



CR-AVE: Jan 2006 TES - Argus



CR-AVE: Jan 2006 TES - ALIAS



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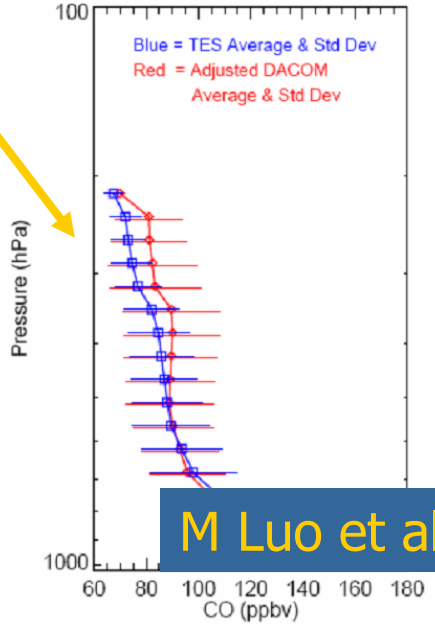
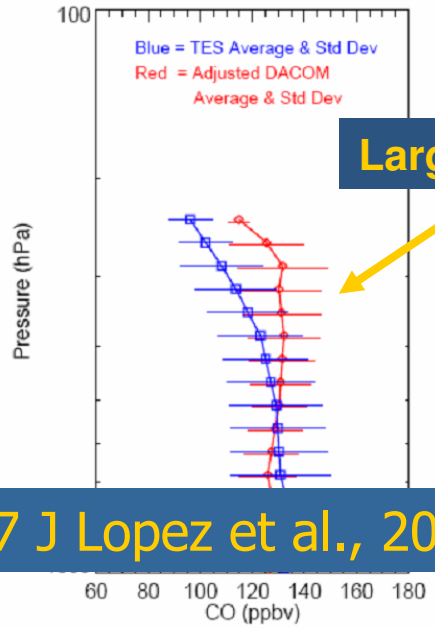
INTEXB-Houston: Mar 06 TES - DACOM



INTEXB-Hawaii: Apr 06 TES - DACOM



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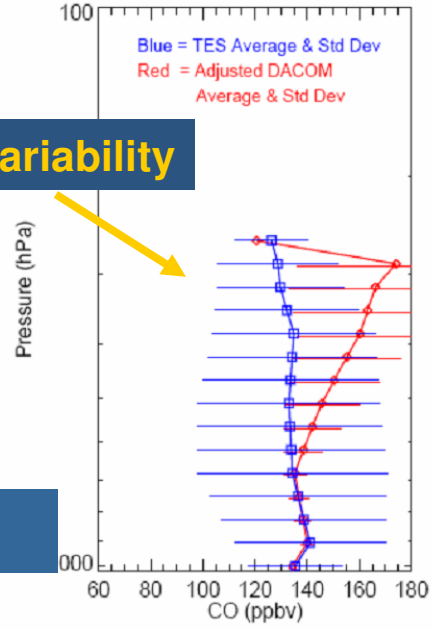


Large CO variability

M Luo et al., 2007 J Lopez et al., 2007

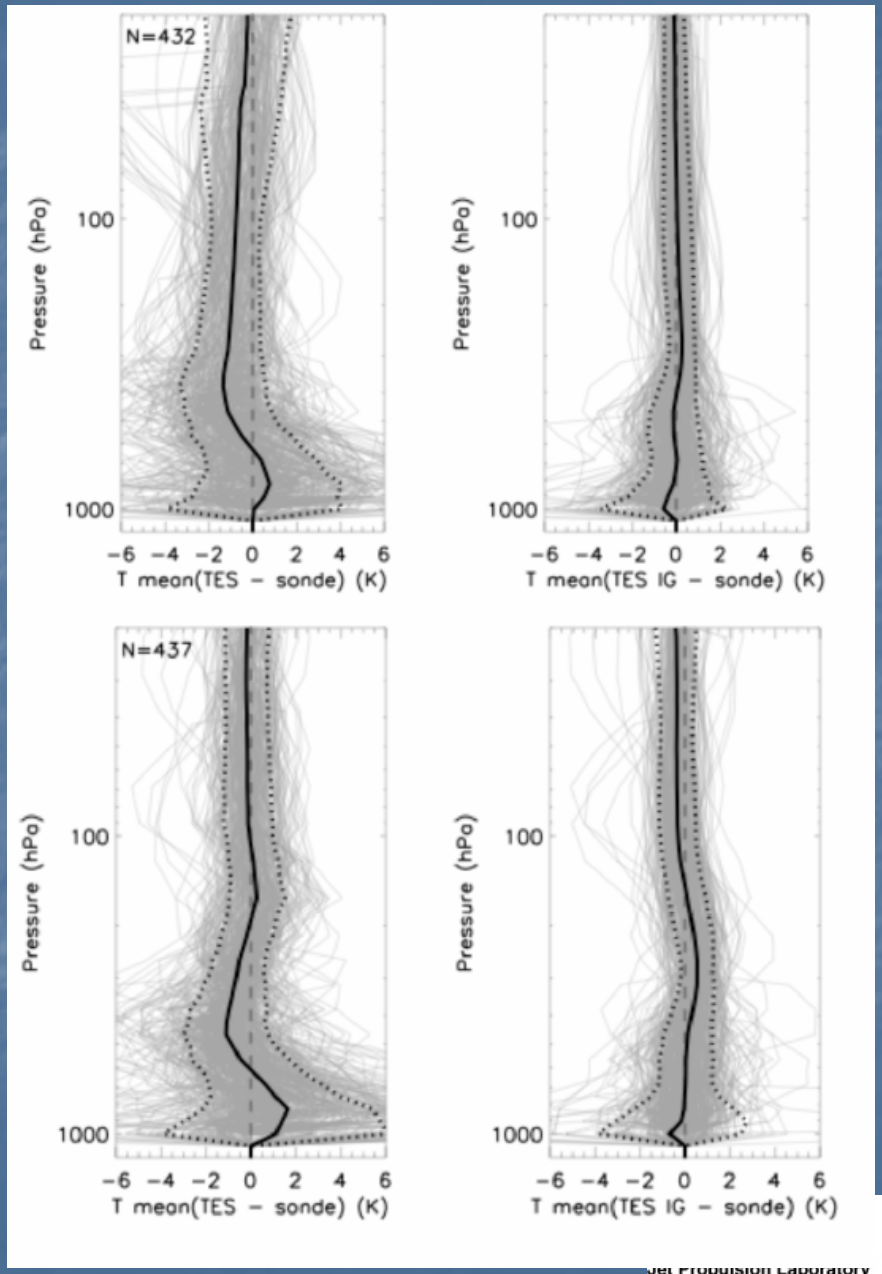
Carbon Monoxide Update
V03 vs V02

- Major change: Relaxed constraints for latitude bins 54-90°N and 54-90°S (same as those of 18N/S – 54 N/S); and
- Small effects from updates for V03 temperature, ozone, water etc.
- Noticeable differences: High latitudes: Larger variability – see sample figures below.
- Comparison to the in situ measurements: No change in conclusions for mid-latitudes (INTEX-B)

M Luo et al., 2007

Nadir Temperature Bias

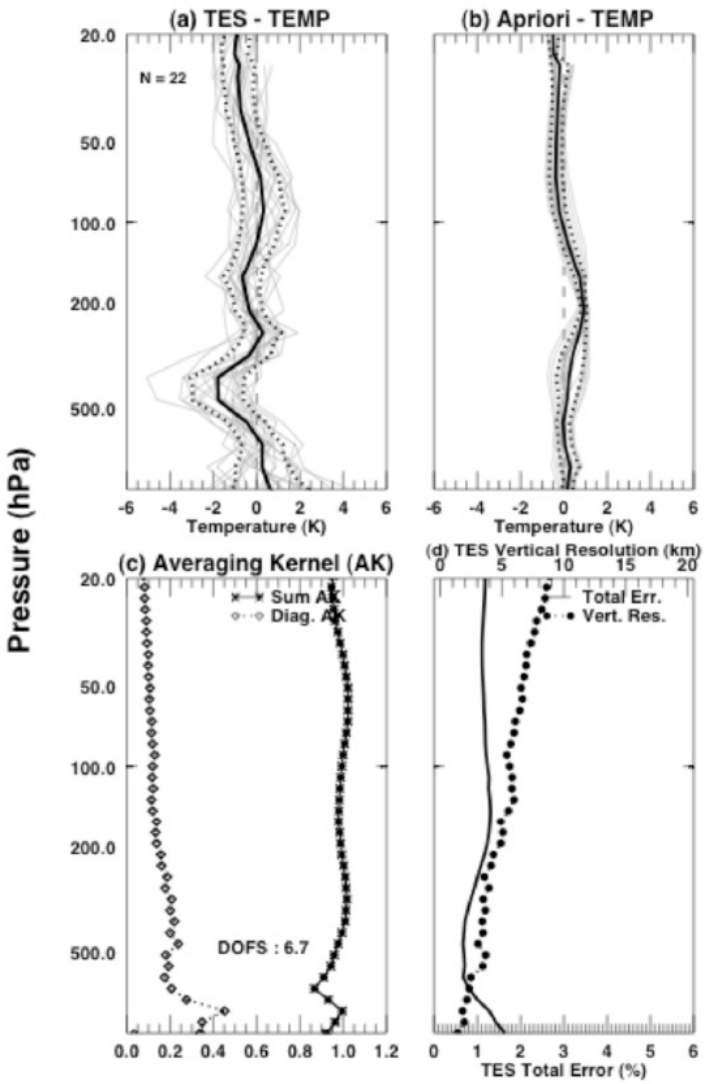
- V003 retrieval uses additional microwindows in the CO2 ν2 band (2B1 filter) at 650 to 800 cm^{-1}
- Top: TES v002 compared with RS-90 and RS-92 sondes (left), and sondes relative to GMAO GEOS-4 (right).
- Bottom: TES v003 compared with RS-90 and RS-92 sondes (left) and sondes relative to GMAO GEOS-5 (right).
- v003 T bias is improved except for cold bias at 400-500 hPa, and warm bias at 800 hPa. GEOS-5 has a warm bias at 300 hPa.



R Herman et al., 2007

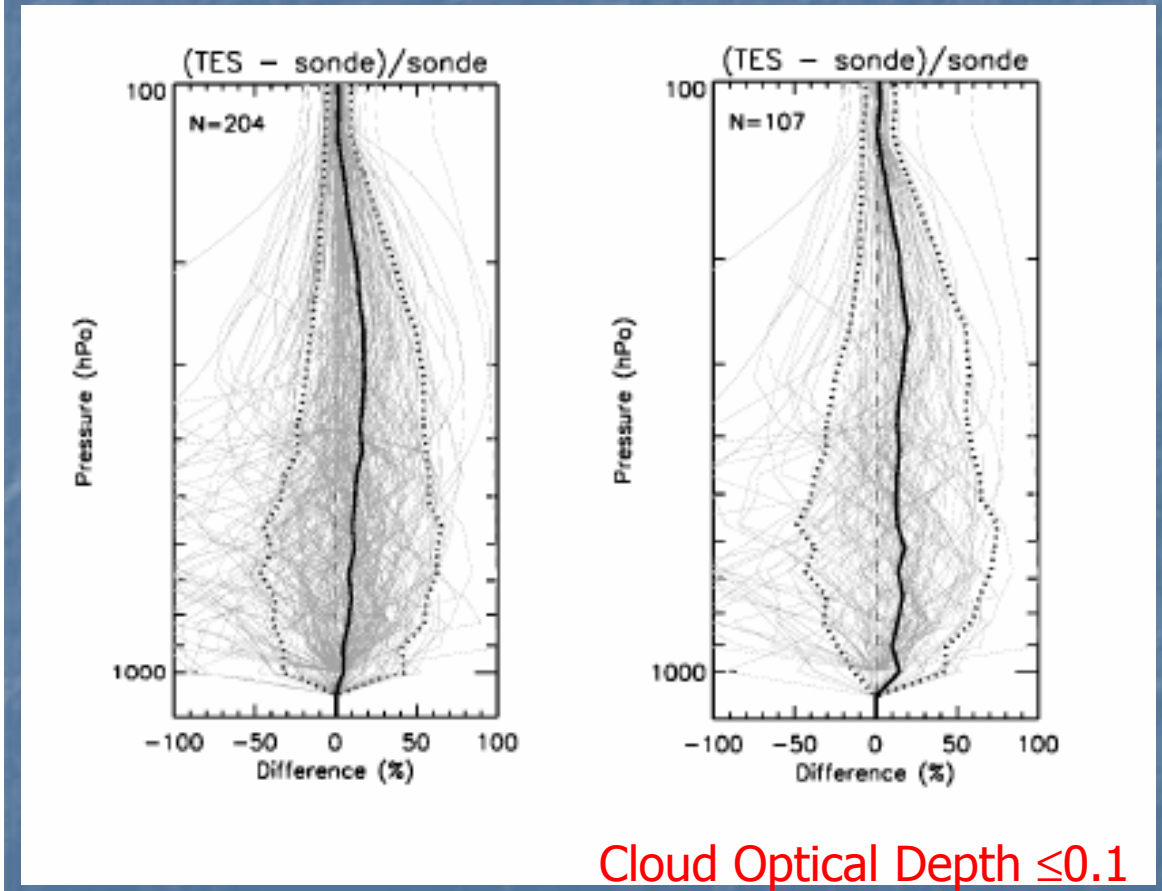
Nadir Temperature WAVES Comparison

- 22 sondes launched during WAVES_2006 compared with TES transect special observations.
- TES v003 temperature bias is improved except for cold bias at 400-500 hPa.
- GEOS-5 has a warm bias at 200 hPa relative to the sondes.



R Herman et al., 2007

Nadir Water Vapor



Cloud Optical Depth ≤0.1

- Global NCEP R90 and R92 sonde comparison
- V002 data
- Coincidence with 100 km and 3 hours
- TES always moist compared to sondes
- 20% bias between 300-400 hPa
- 10-15% bias in lower troposphere
- Improvement when filtered for cloud optical depths ≤ 0.1
- Known errors with sondes make it difficult to draw meaningful comparisons

M Shephard et al., 2007

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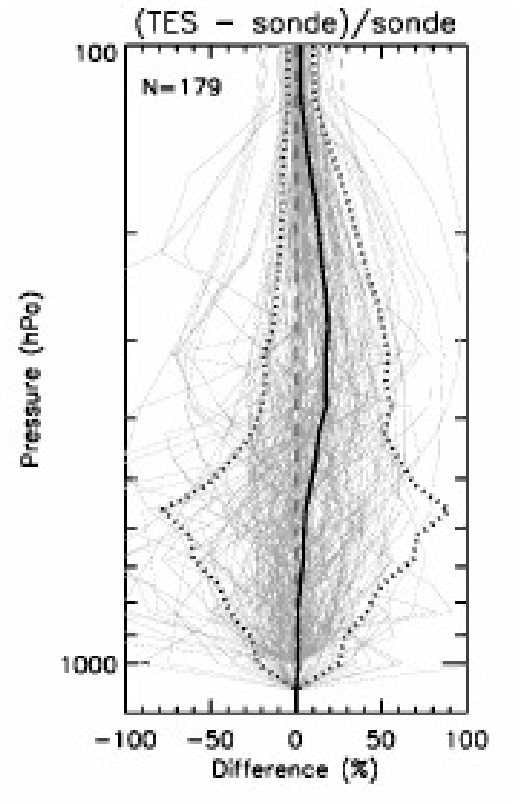
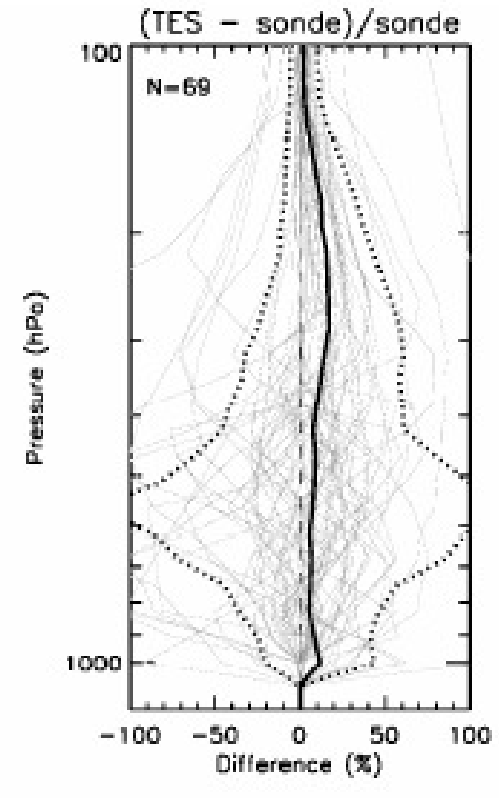
Nadir Water Vapor





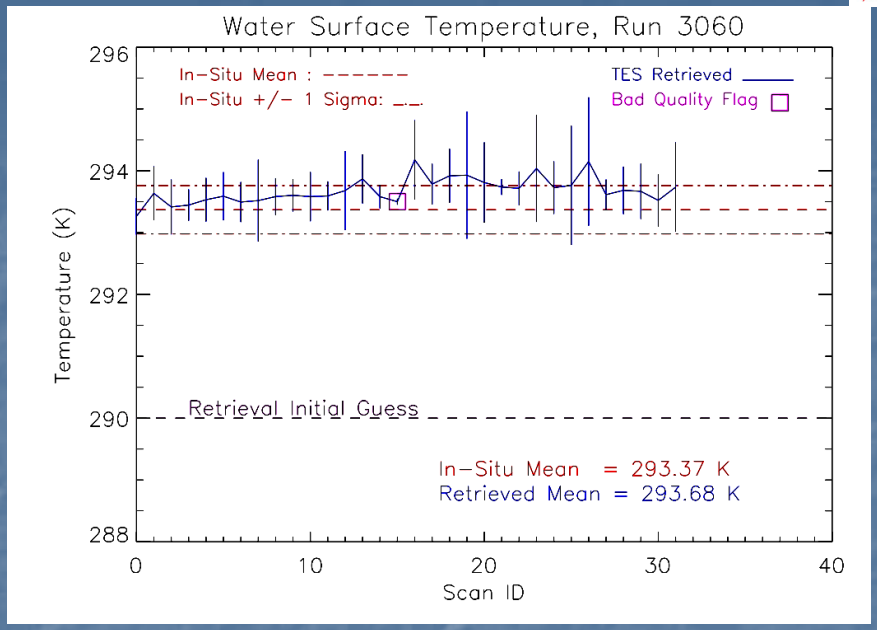
Cloud Optical Depth ≤0.1

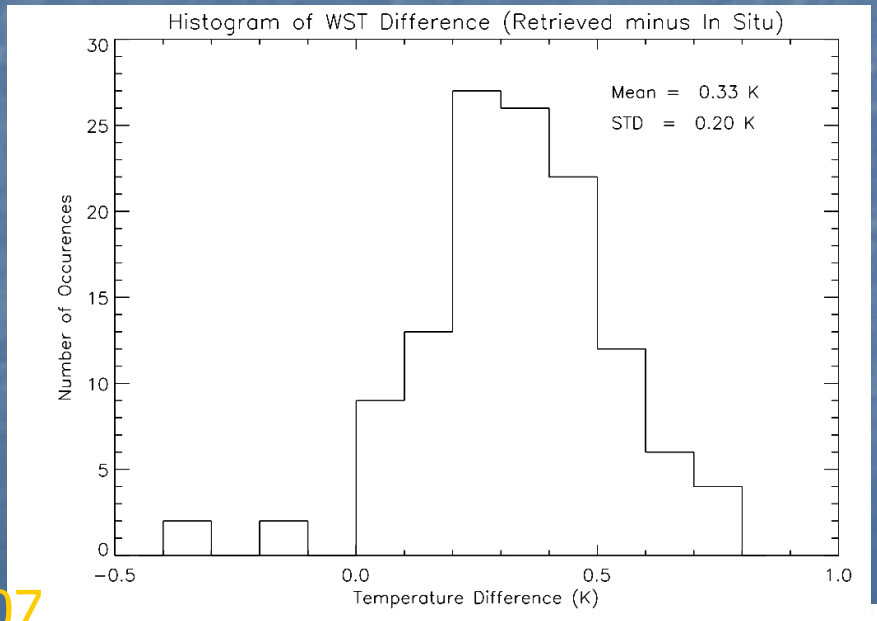
- V003 data
- 5% improvement below 500 hPa over V002
- 5-10% difference below 700 hPa
- Increases to ~20% at 400 hPa
- Comparison to CFH measurements (not shown)
  - 5-10% below 700 hPa
  - 5-40% for 300-700 hPa
- Radiance closure experiment (not shown) suggest differences in middle/upper troposphere cannot be fully accounted for by known systematic error
  - Spectroscopic? Sampling Errors?

M Shephard et al., 2007

SST Temperature

- V002 TES data
- Comparisons of TES clear sky observations to Reynolds Optimally Interpolated data
  - 0.04 K (Day)
  - -0.17 K (Night)
- Comparisons to AMSR-E
  - -0.06 K (Day)
  - -0.09 K (Night)
- Clear sky RMS Error of 0.2 – 0.45 K with annual variation of 0.1 K
- Comparison to in situ measurements on Lake Tahoe
  - Bias of 0.33 K
- Changes in SST for V003 are minor



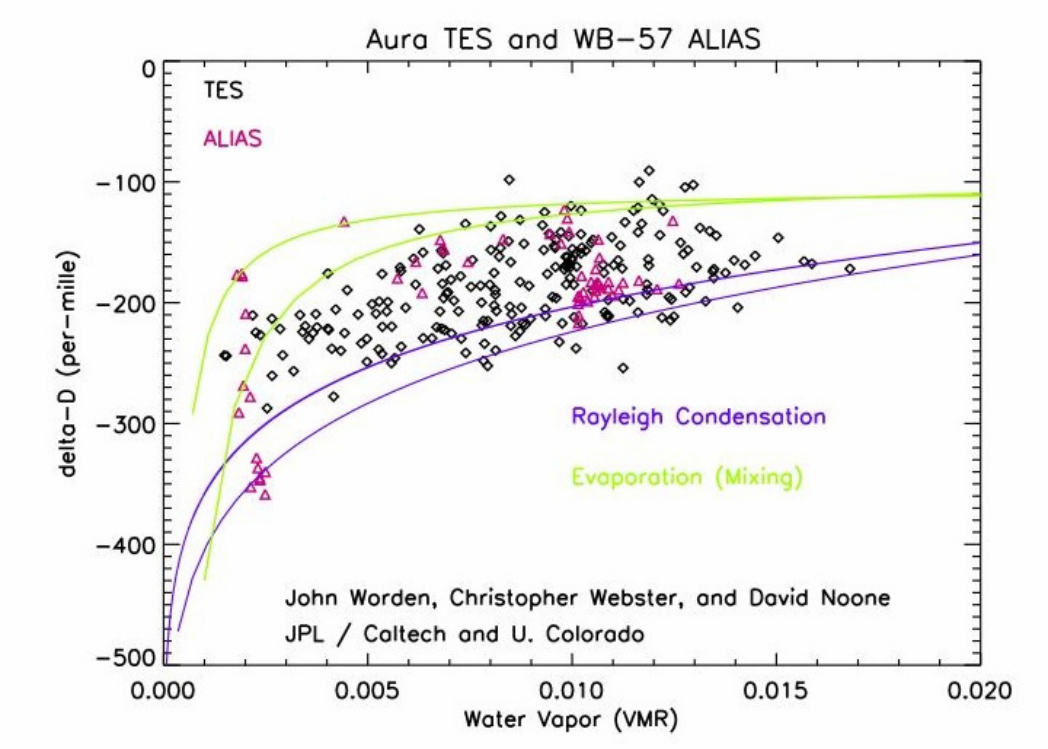


D Trembley, M Lampel et al., 2007

Jet Propulsion Laboratory
California Institute of Technology

Validation of TES HDO/H2O

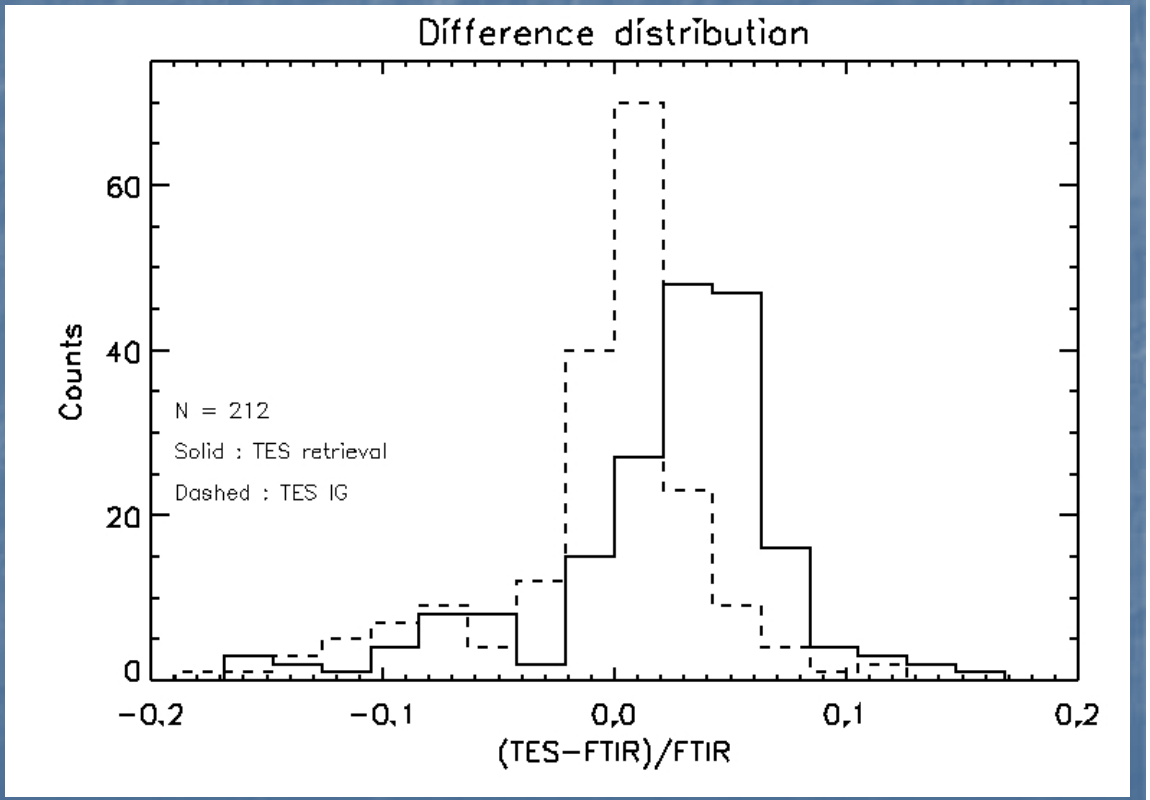
- Based on limited data for validation and model comparisons TES measurements are biased by ~5%
- Similar distributions when compared to ALIAS
- Similar global distributions to those from models
  - Increased depletion with latitude
  - Decreased depletion near regions of convection



J Worden et al., 2007

Methane

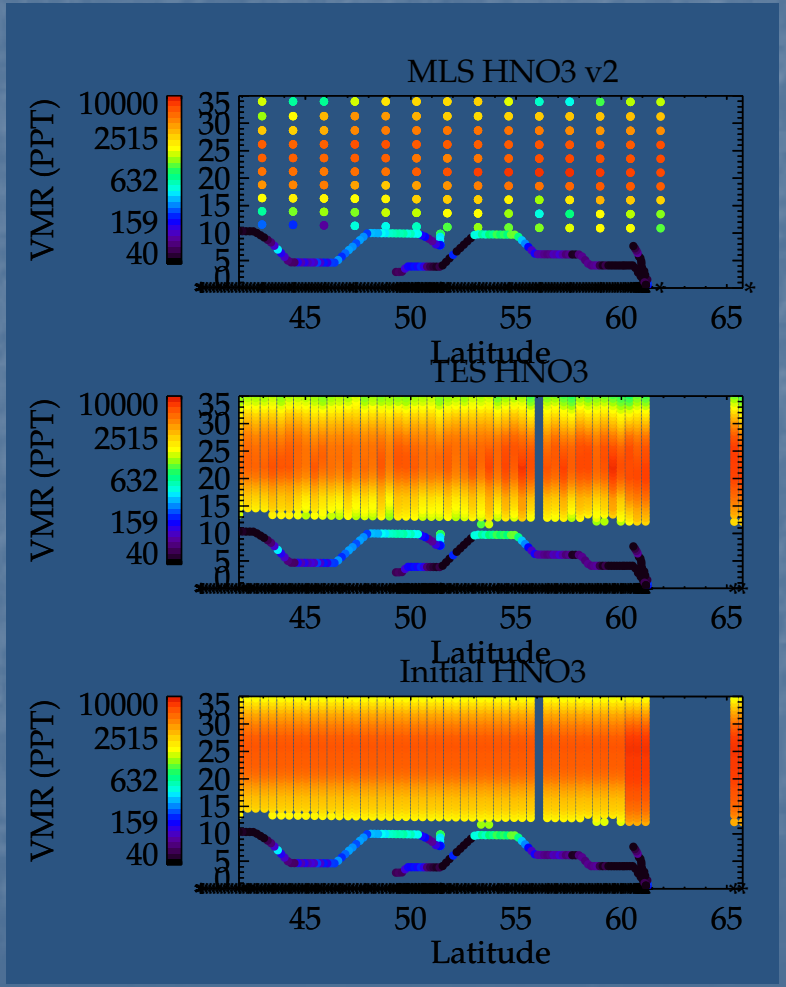
- Initial comparisons to DACOM (INTEX-B) and ground based FTIR (column)
- TES is ~5% high in column measurements
- Bias is seen between 150-500 hPa when compared to DACOM during INTEX-B
- Limited validation data in free troposphere



B Fisher

Nitric Acid

- Comparison with MLS and SAGA (DC-8) during INTEX-B
- TES cannot reach the troposphere due to limitations of clouds
- Comparison with MLS show similar spatial patterns in the stratosphere
- Comparisons with CIMS (WB-57) during CR-AVE show consistent spatial distributions (not shown)

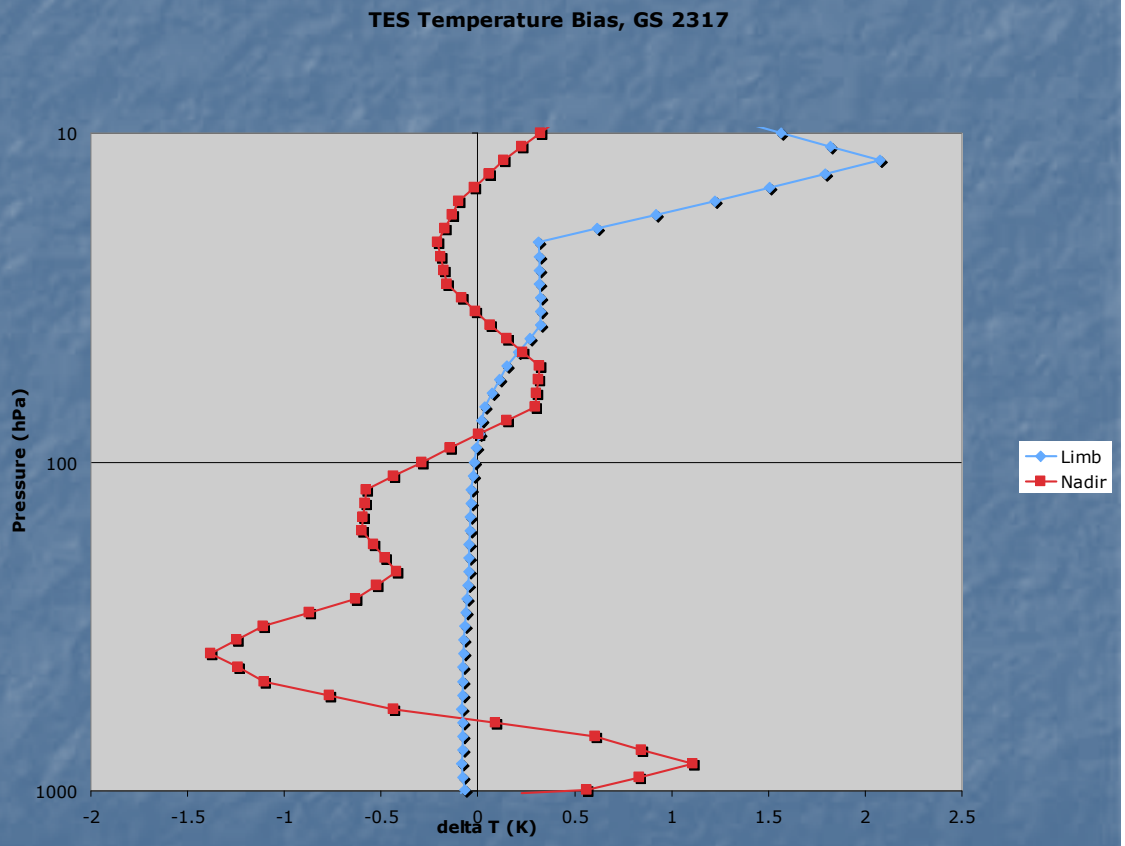


S Kulawik

Jet Propulsion Laboratory
California Institute of Technology

Limb Temperature

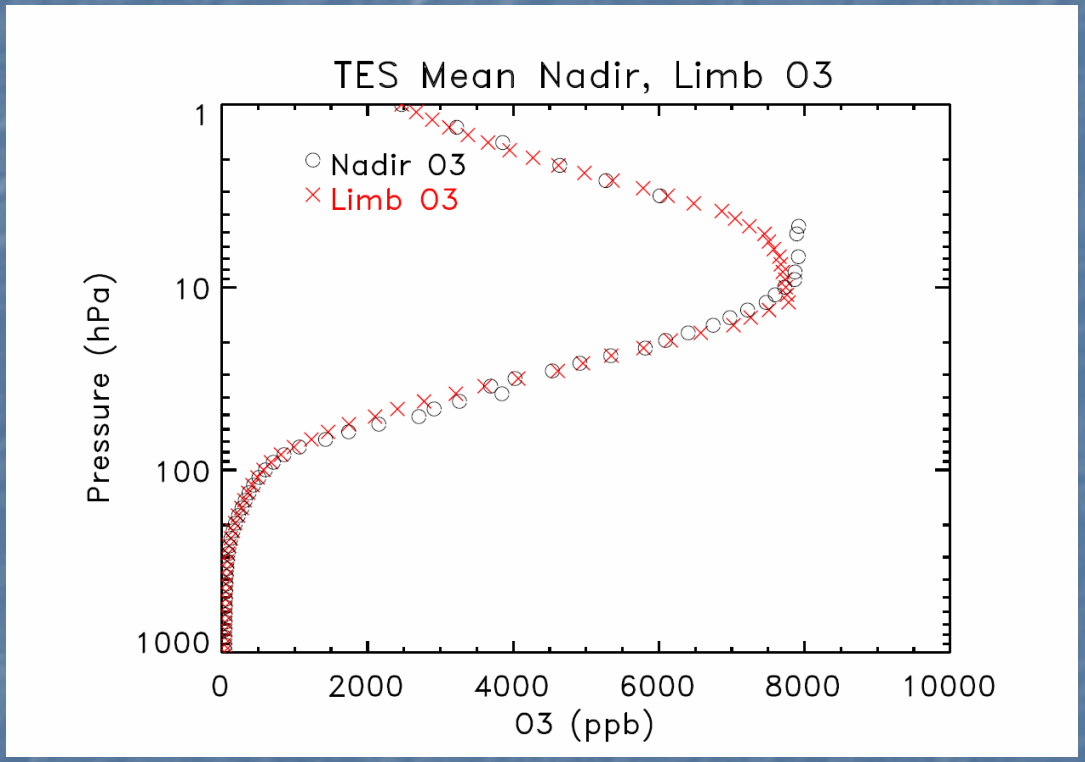
- TES cannot reach the troposphere due to limitations of clouds
- Limb data shows a warm bias in the lower stratosphere that increases with altitude
- Spatial patterns in the nadir and limb data are similar



R Herman

Limb Ozone

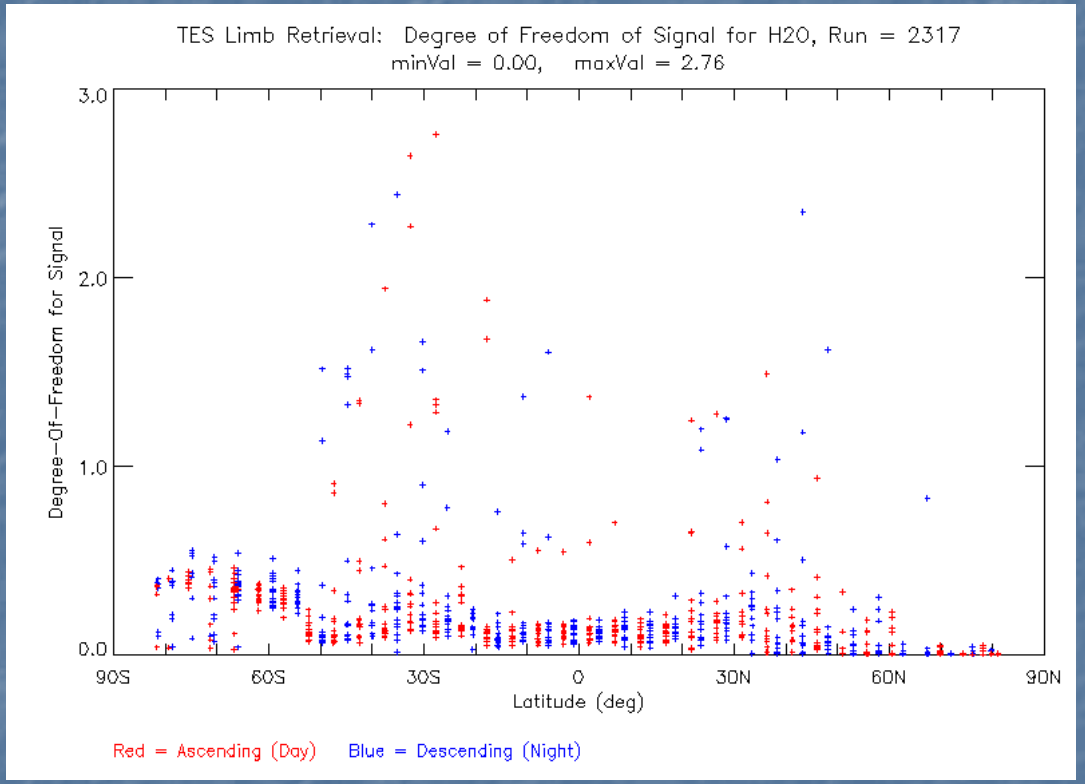
- Comparison with TES nadir profiles
- Spatial patterns in the nadir and limb data are similar
- TES limb values lower than nadir in regions of peak sensitivity for both measurements



R Herman

Limb Water

- Working to understand our limb water retrievals better
- Poor throughput
- Poor sensitivity



R Herman

TES Validation Data Requirements

- TES team feels the current validation data sets are sufficient for current and future validation analyses but …

Species	Requested Data	Reason
L1B Radiances	AIRS, Scanning-HIS	More Scanning-HIS data for monitoring of L1B data quality
TATM, H2O, O3	Ozonesondes, CFH sondes	CFH sondes – Clear sky, Ocean scenes (Separation of effects for systematic errors – AER)
Nadir O3	Ozonesondes	High latitude sondes to improve statistics (ARCTAS)
HDO	?	Data between 500-700 hPa (ARCTAS)
CH4	DACOM	Profile data

Future Validation Analyses

- High bias in nadir ozone, improvement in nadir temperature profiles
  - Use current set of sonde measurements
  - TES V004 data → 2008
- Continued validation of limb products
- HDO, Methane
- Nadir ozone in the stratosphere, limb ozone using MLS, HIRDLS
- Open to other ideas and collaborations for "science related" validation analyses

Summary

- All* TES nadir products have been validated and can be used in scientific studies
  - *Methane is still problematic
  - Documented in JGR papers and Validation Report
- Limb products provisionally validated
- V003 TES data is an improvement for nadir temperature, nadir water vapor and sea surface temperature
  - Less clear is how much ozone has improved
  - Carbon monoxide has increased variability in polar regions

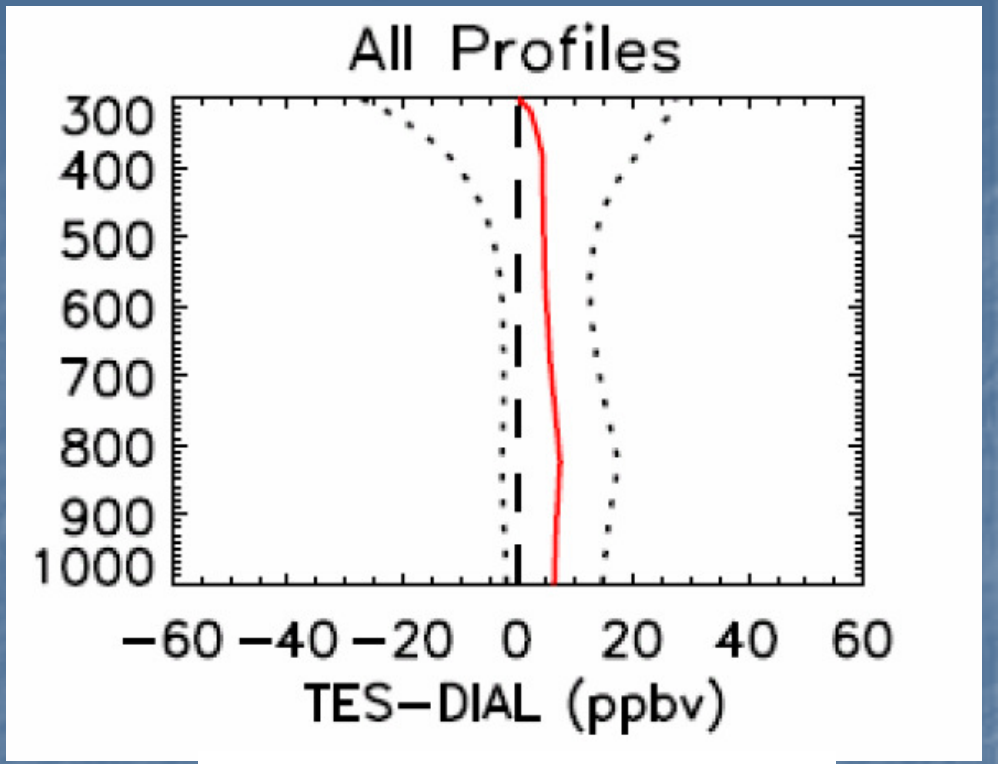
Extra

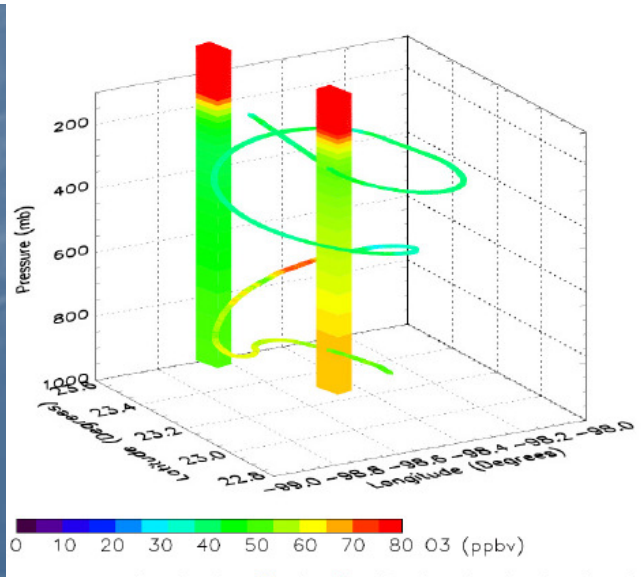
2007 – Validation Activities

- SAUNA-2 (February – March)
- INTEX-B Meeting (March 2007)
- Papers for Aura Special Issue of JGR-Atmospheres (April)
- Texas AQS Meeting (May)
- WAVES 2007 (July – August)
- TC-4 and Ticosonde (July-August)
- MOHAVE (October)
- Aura Validation WG Meeting (October)

TES O3 Validation: Aircraft

- 225 coincident profiles with DIAL Lidar during INTEX-B
- TES V002 Data
- High bias of ~7 ppbv
- Spatial/Temporal mismatches affect the observed differences
- Good comparisons with FASTOZ in homogeneous fields



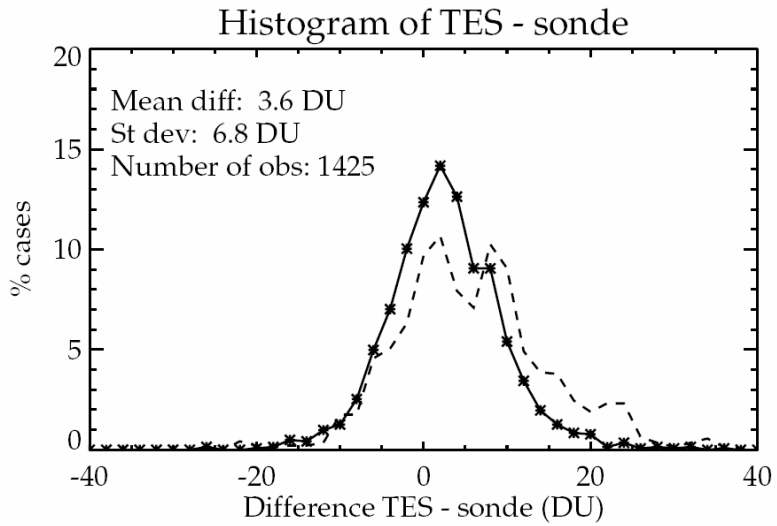


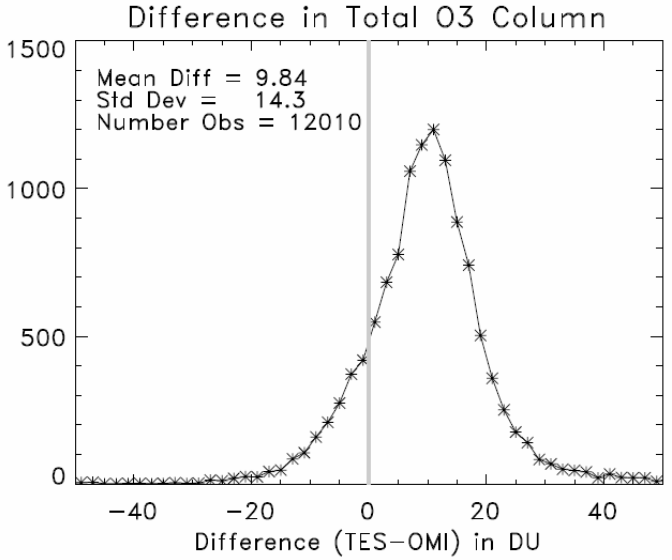
Richards et al., 2007

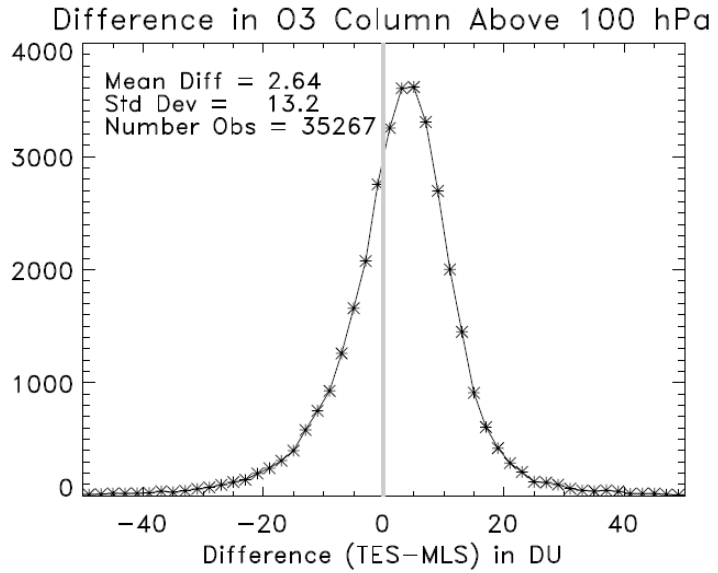
ion Laboratory
stitute of Technology

Ozone Column

- TES biased high in total O3 column by 8-15 DU
  - Related to differing sensitivities
  - Much higher than the difference in IG
  - Some latitudinal variability
- TES biased high compared to MLS above 100 hPa by 3-5 DU
- High bias of ~4 DU in tropospheric column compared to sondes
  - Consistent with profile comparisons

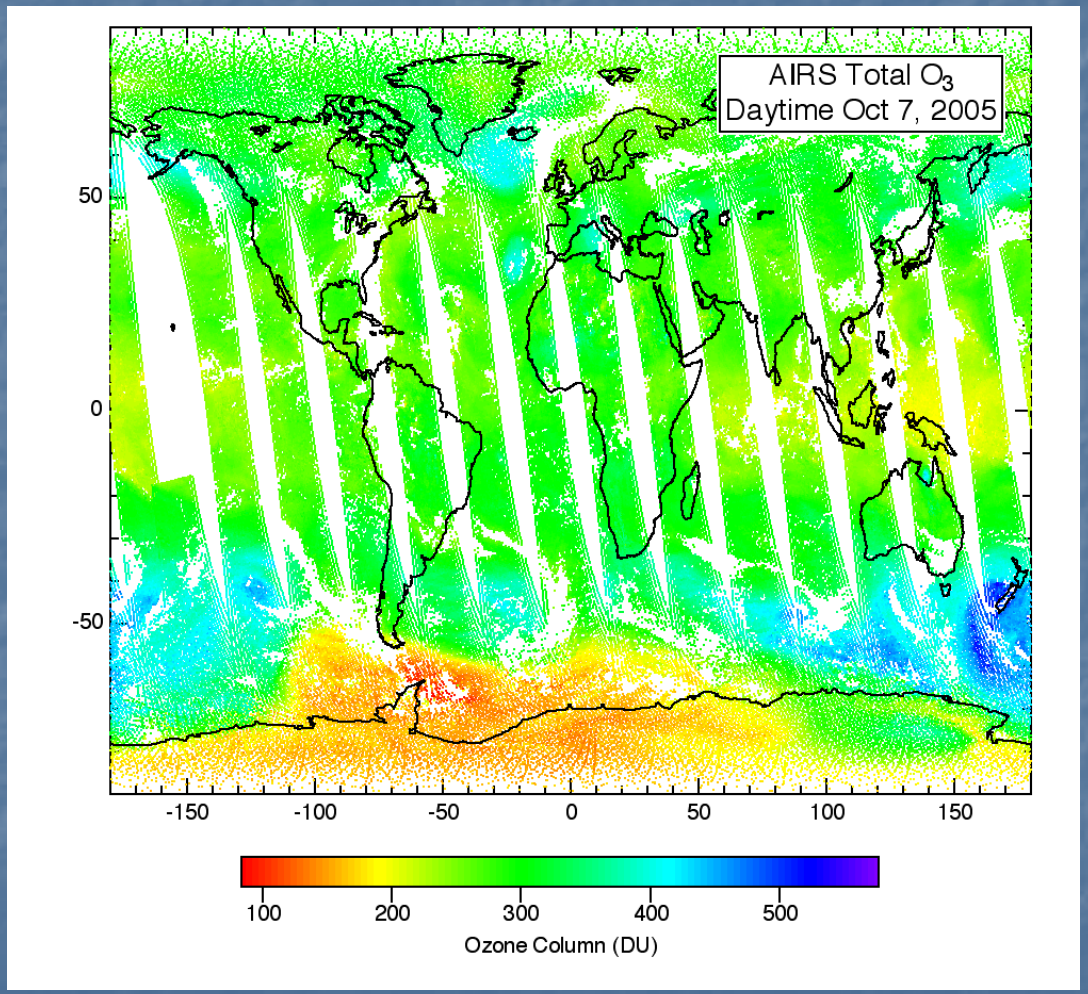


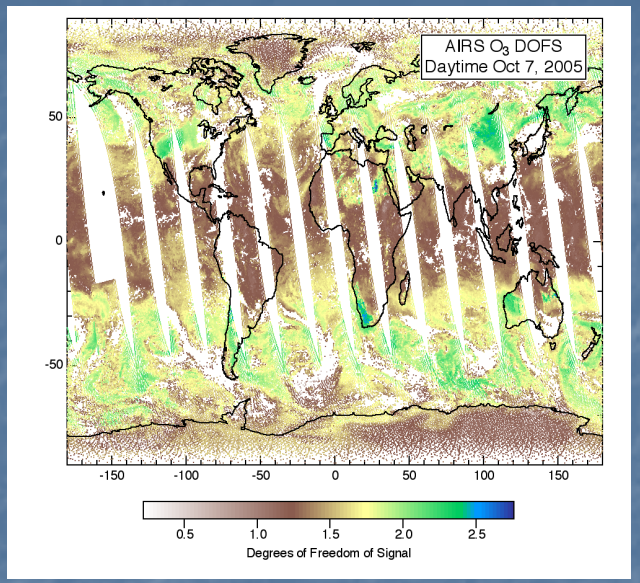


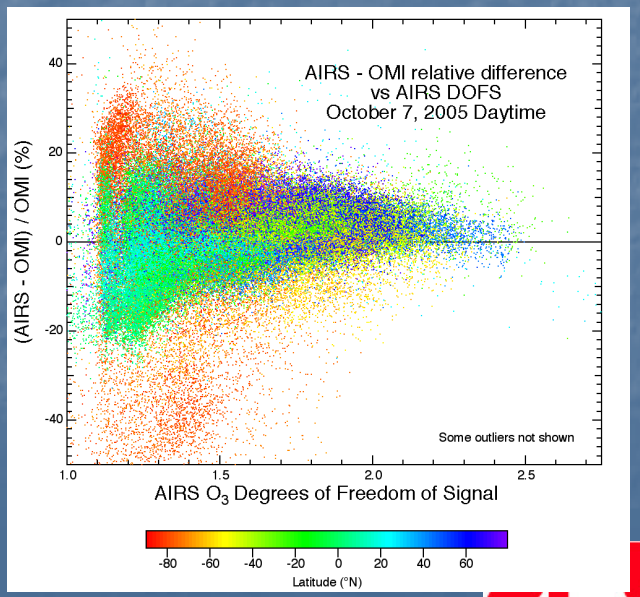


Osterman et al., 2007

AIRS Total Column Ozone - Oct 7, 2005

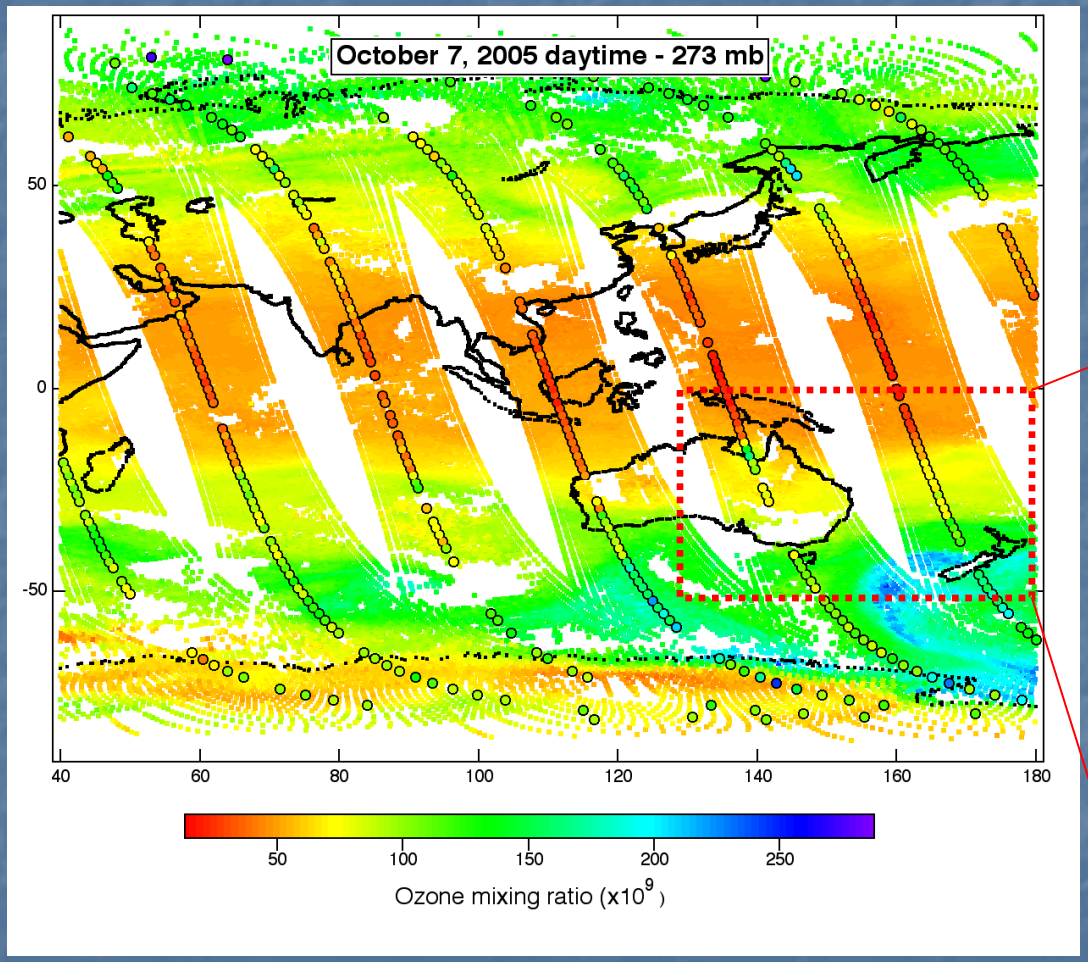


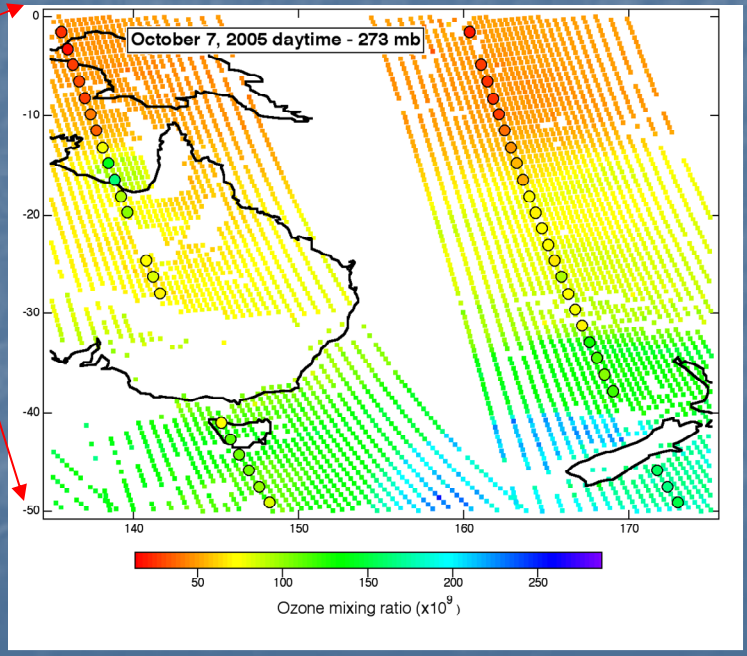




B Irion

AIRS and TES Ozone at 273 mb - Oct 7, 2005





B Irion

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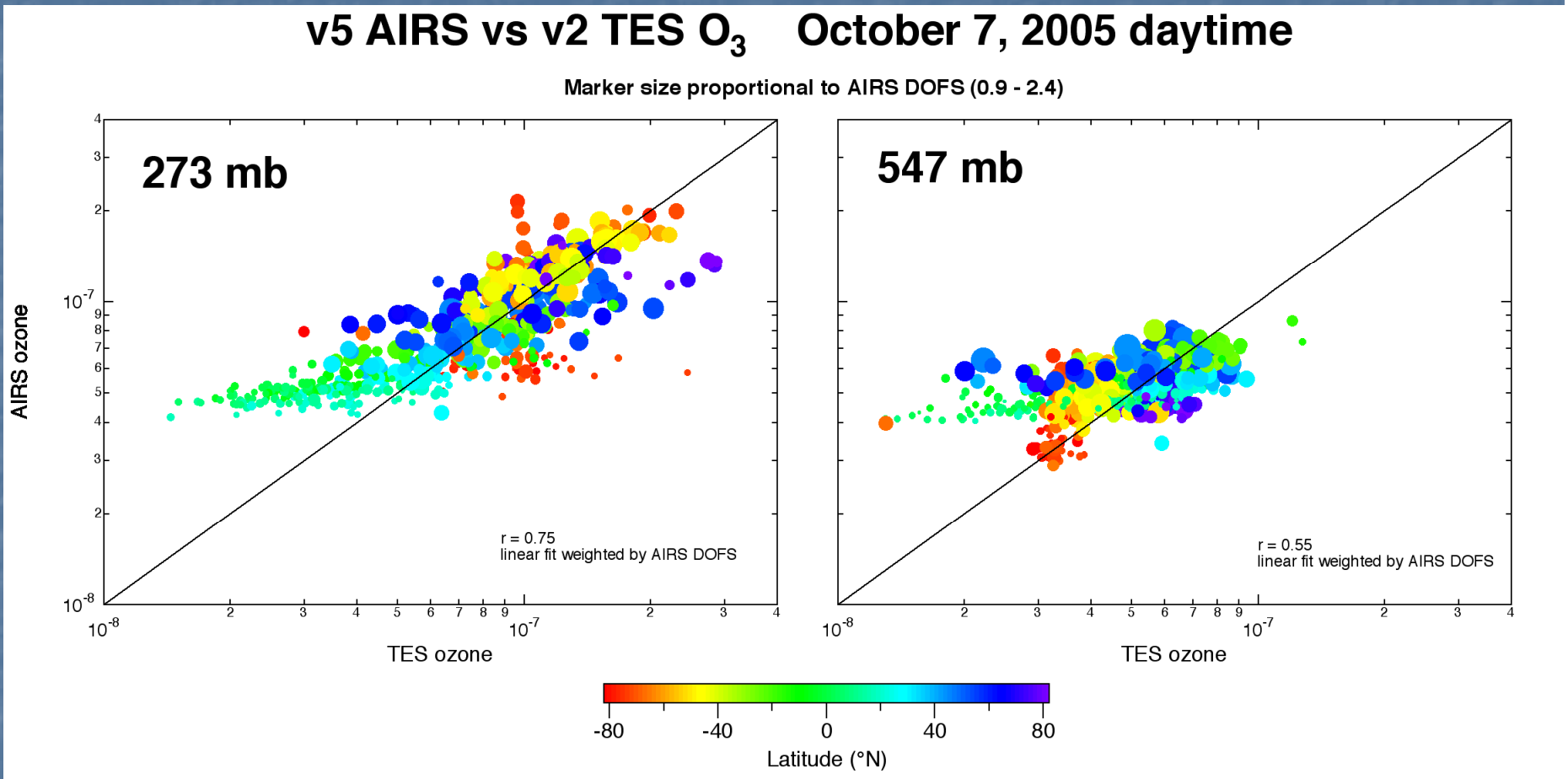
AIRS and TES Ozone at 273, 547 mb - Oct 7, 2005



B Irion

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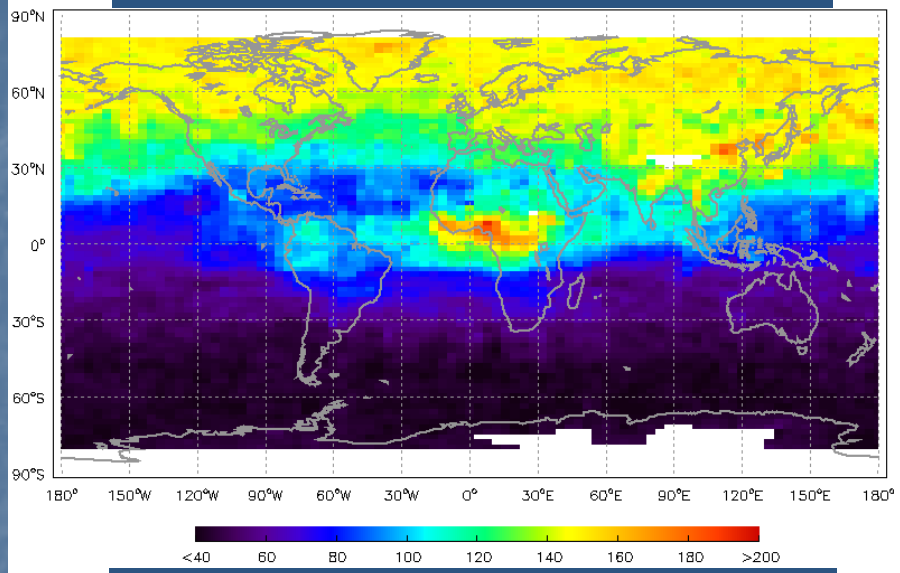
Carbon Monoxide

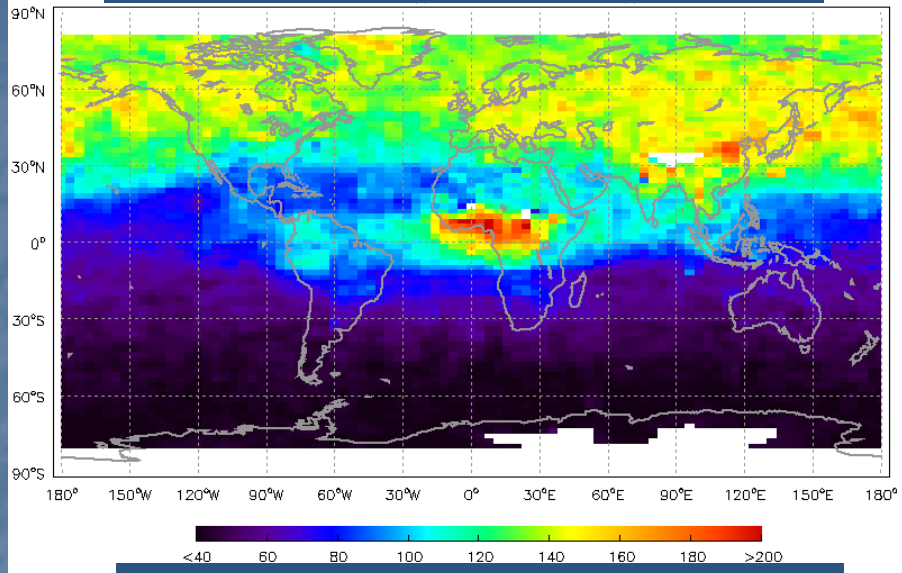
Comparison Sources	Progress	Results / problems
MOPITT	▪ Data from Sept 20-21, 2004. JGR paper under review ▪ Monthly	▪ Good agreement in global patterns ▪ Influence of *a priori* constraints on CO retrievals of both instrument. The agreement much improved after adjusting the retrieval with *a priori* info. ▪ MOPITT will release V4 data
ACE MLS AIRS	▪ Time trends with ACE data in upper trop ▪ One day 2004 data with MLS in upper trop ▪ AIRS in preparation	▪ Good agreement with ACE ▪ MLS being too high ▪ Understand AIRS AK
AVE (Argus) CR-AVE (Alias)	▪ Comparisons made AVE-04; paper will go to special JGR issue	▪ Agreement within CO area variability and the estimated errors of 10-20%.
INTEX-B (DACOM)	▪ Comparisons made; paper will go to special JGR issue	▪ Agreement within CO area variability and the estimated errors of 10-20%. in Houston area.
MOZAIC	▪ Comparisons made Sept 04 – May 05	▪ Agreement within CO area variability and estimated errors of 10-20% in most airports. ▪ Waiting for data after May 2005.

TES CO Monthly Means: V002 vs V003

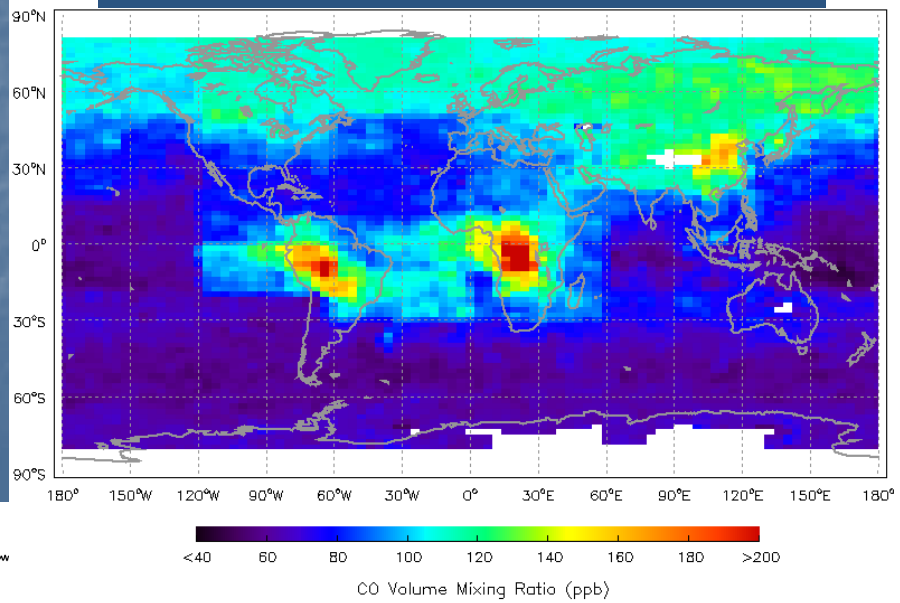
V002: Feb 2006, P = 681.3 hPa



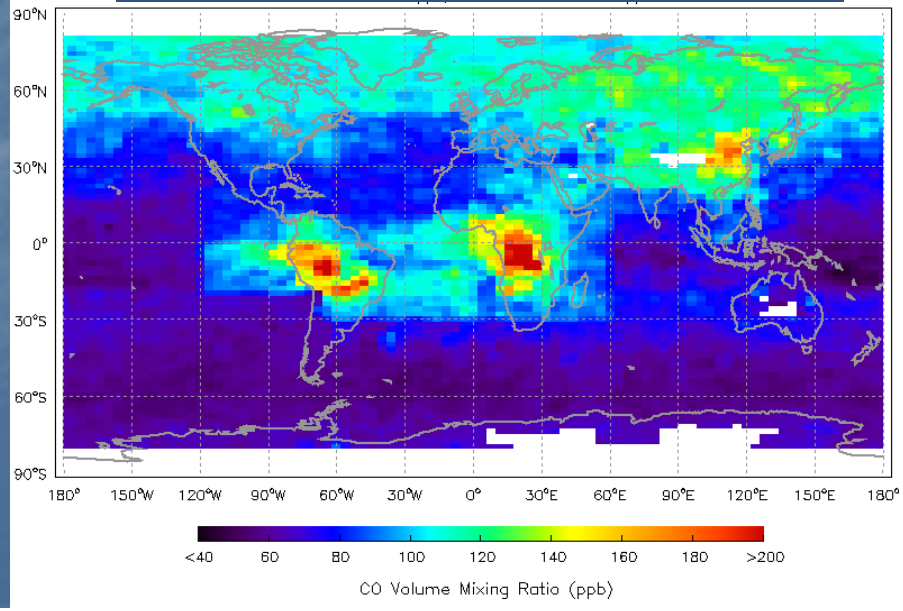
V003: Feb 2006, P = 681.3 hPa



V002: Aug 2006, P = 681.3 hPa



V003: Aug 2006, P = 681.3 hPa



TES CO Monthly Means: V002 vs V003

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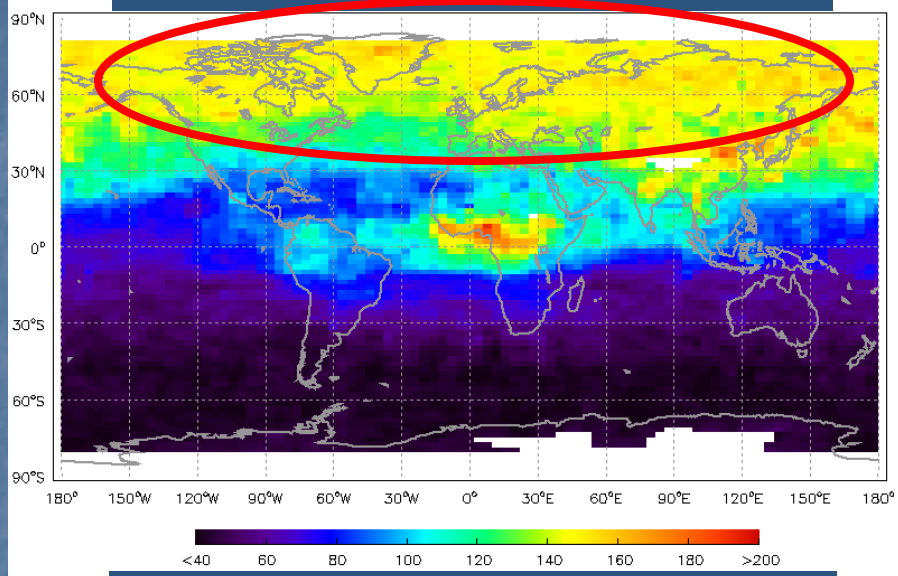
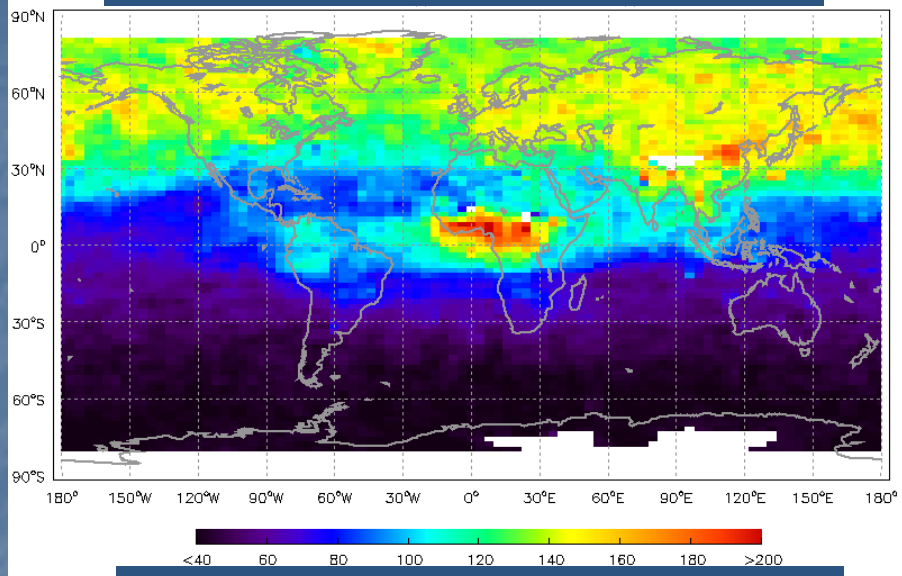


V003: Feb 2006, P = 681.3 hPa



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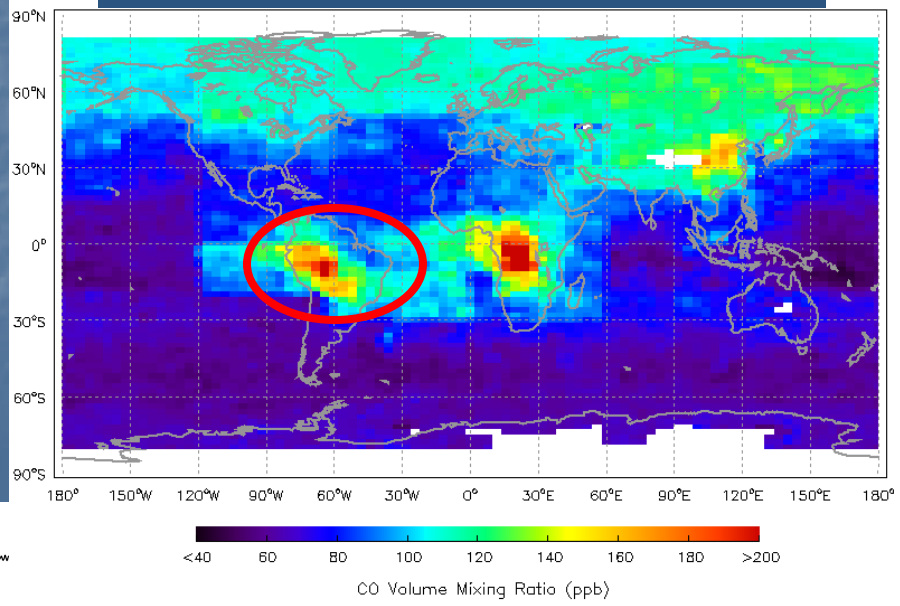
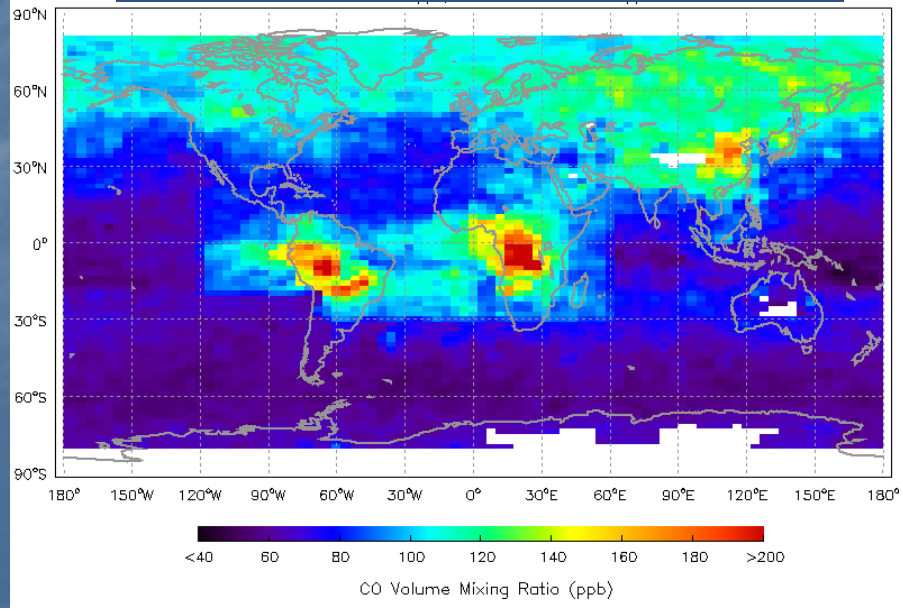
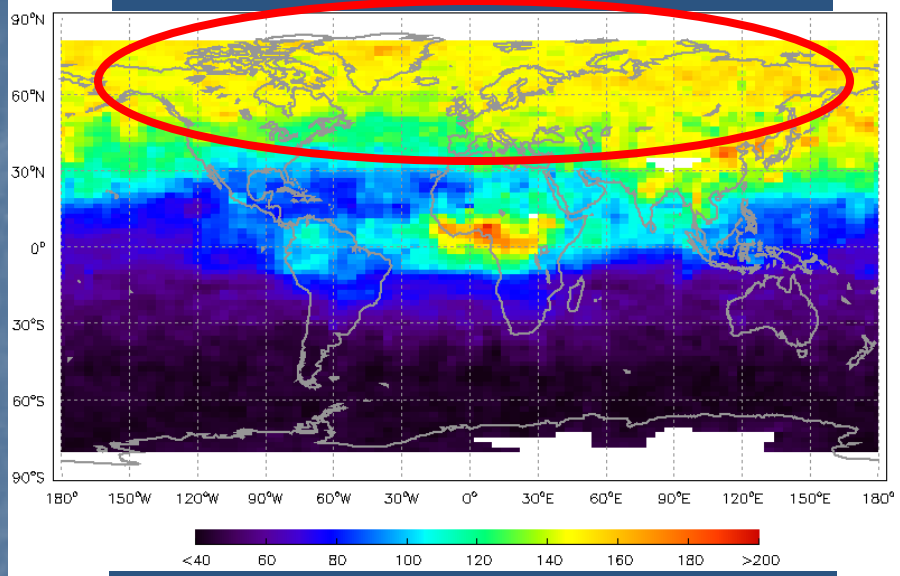


V003: Aug 2006, P = 681.3 hPa

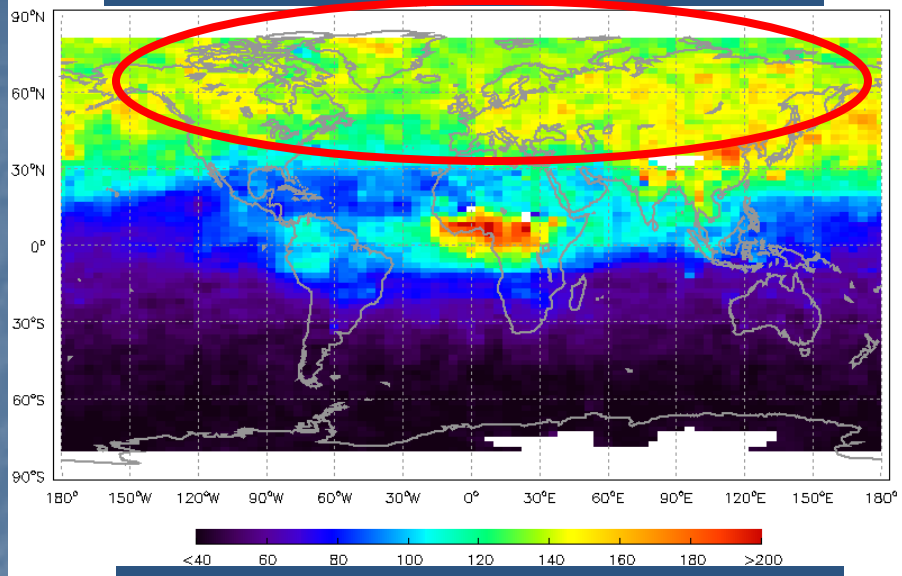


TES CO Monthly Means: V002 vs V003

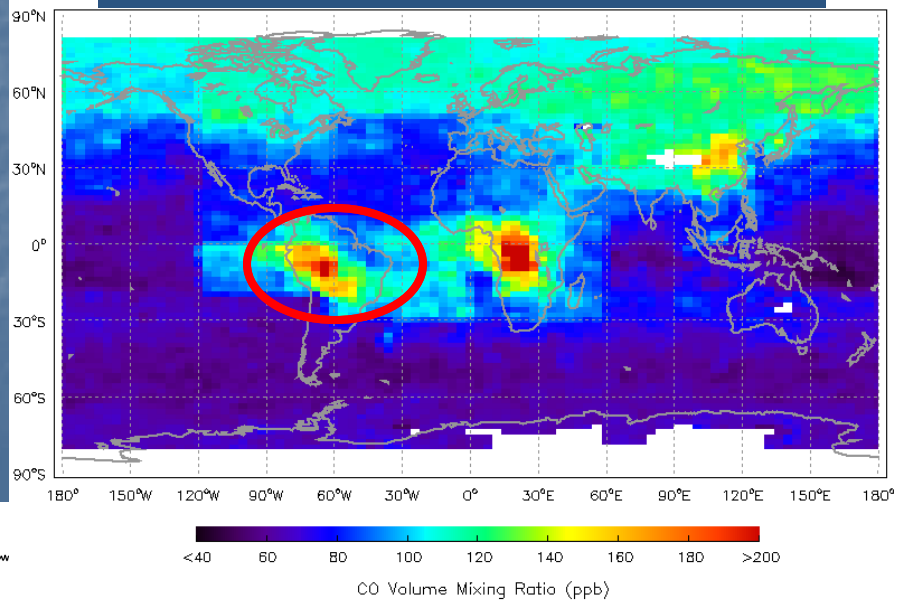
V002: Feb 2006, P = 681.3 hPa



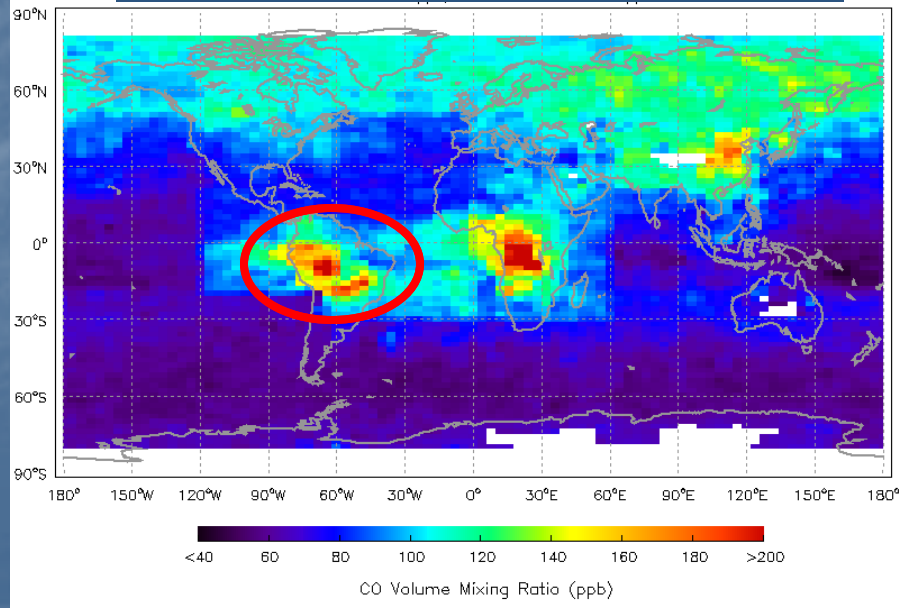
V003: Feb 2006, P = 681.3 hPa



V002: Aug 2006, P = 681.3 hPa

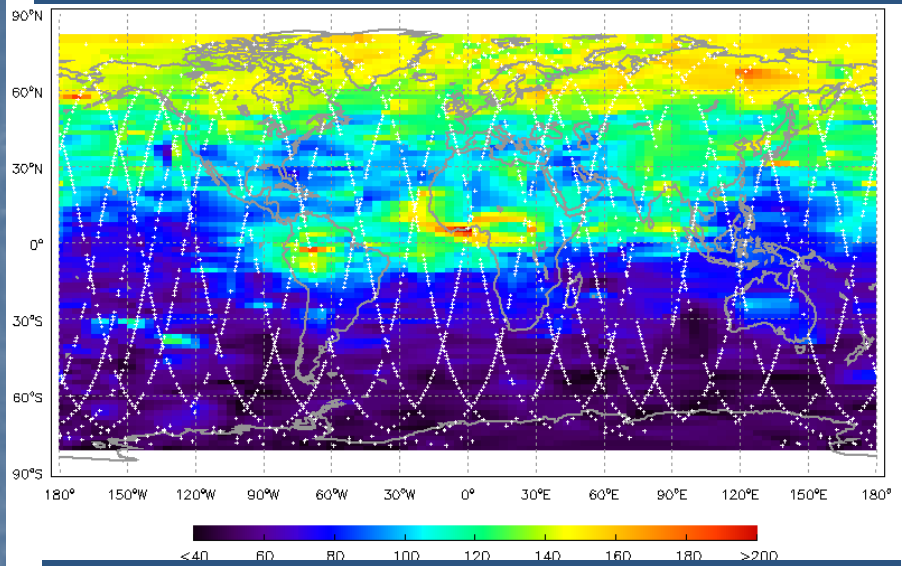


V003: Aug 2006, P = 681.3 hPa



TES CO Global Surveys: V002 vs V003

V002: Dec 16-17, 2006, P = 681.3 hPa



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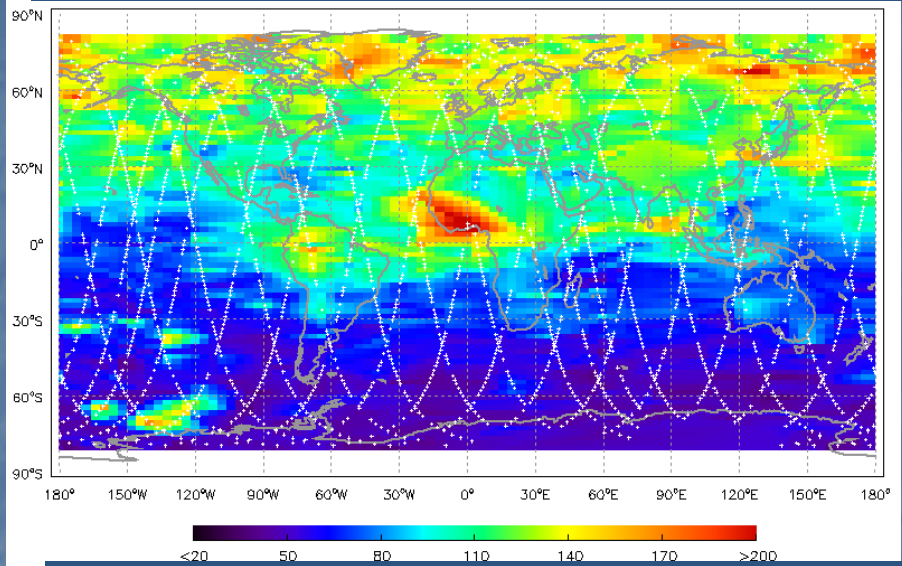
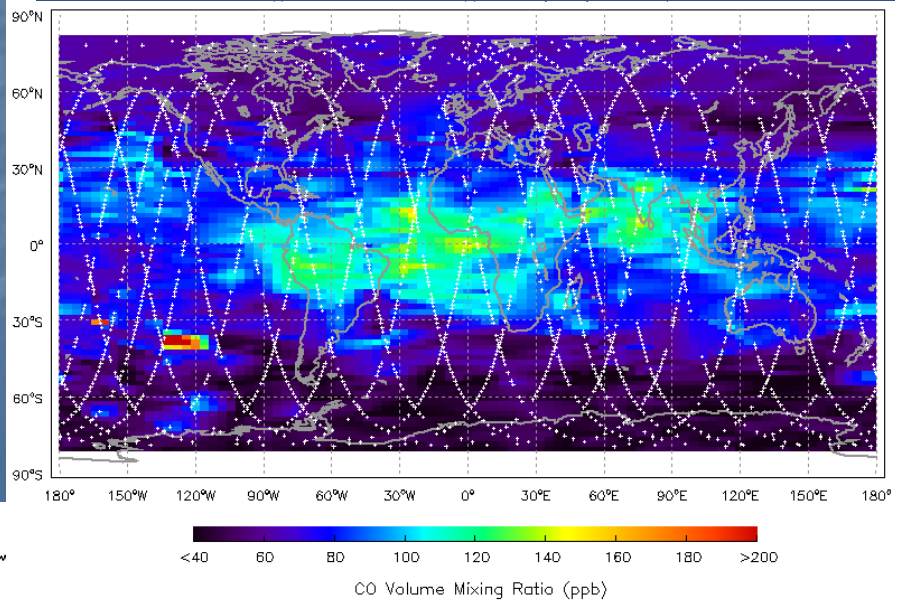
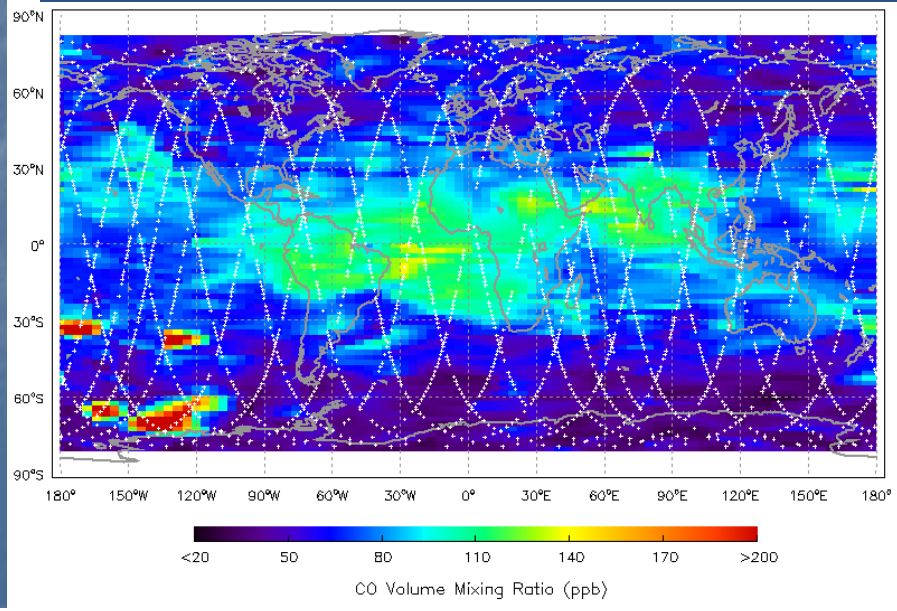


V002:Dec 16-17, 2006, P = 215.4 hPa

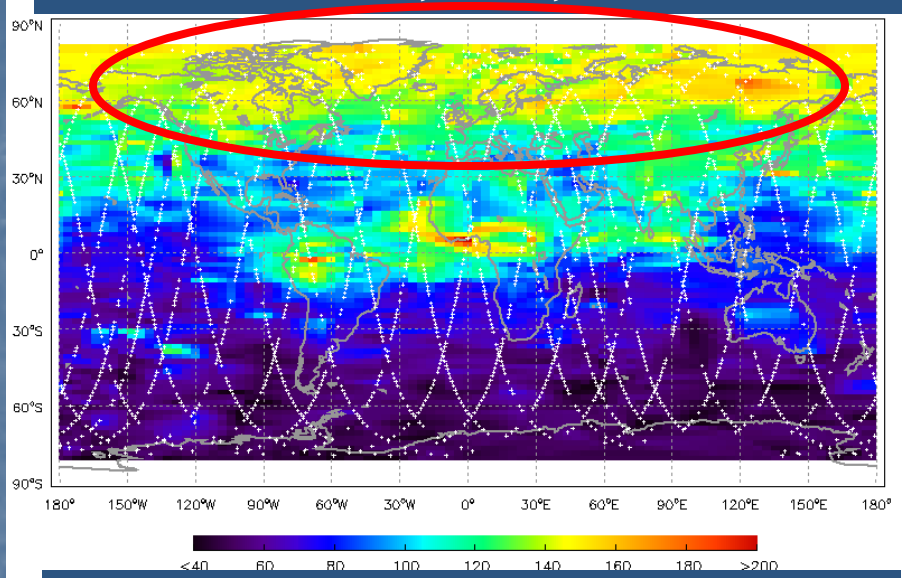


V003:Dec 16-17, 2006, P = 215.4 hPa

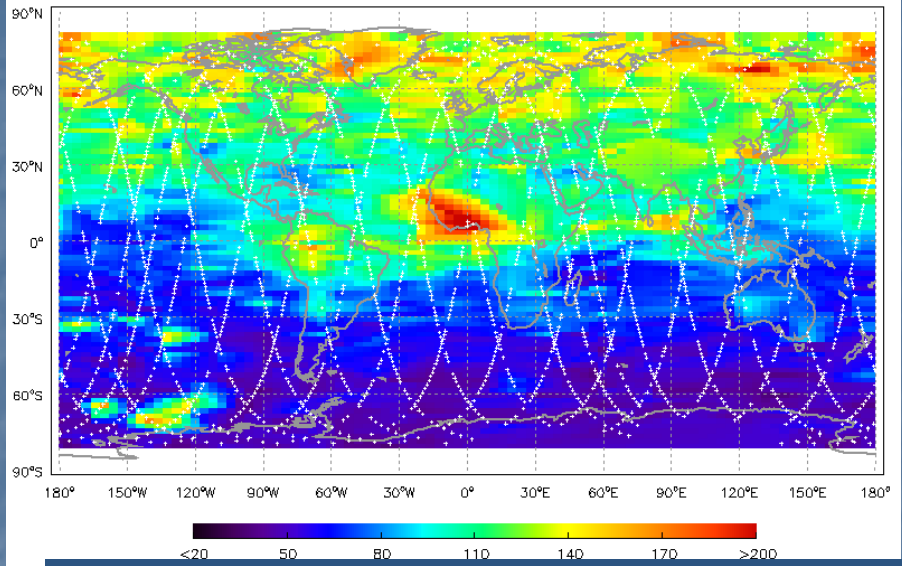


TES CO Global Surveys: V002 vs V003

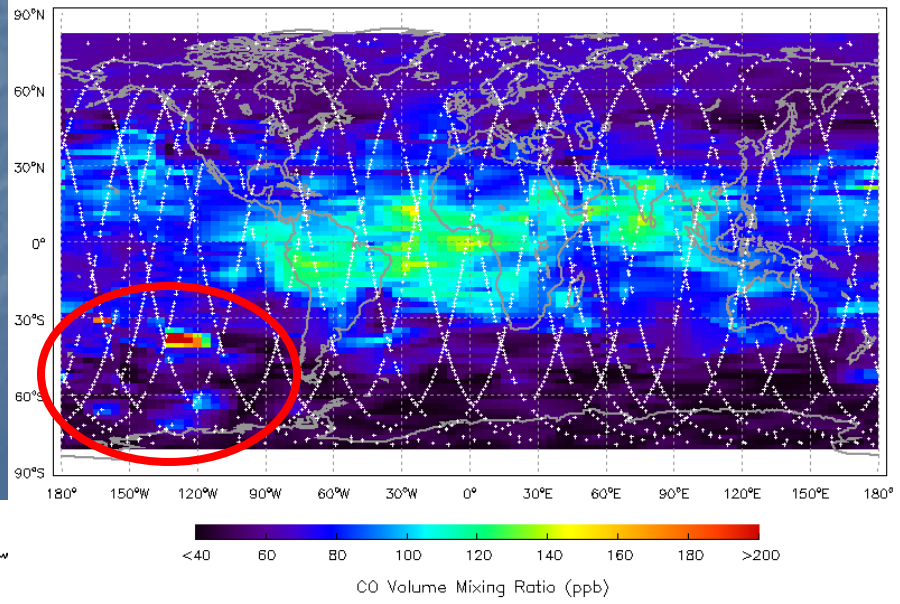
V002: Dec 16-17, 2006, P = 681.3 hPa



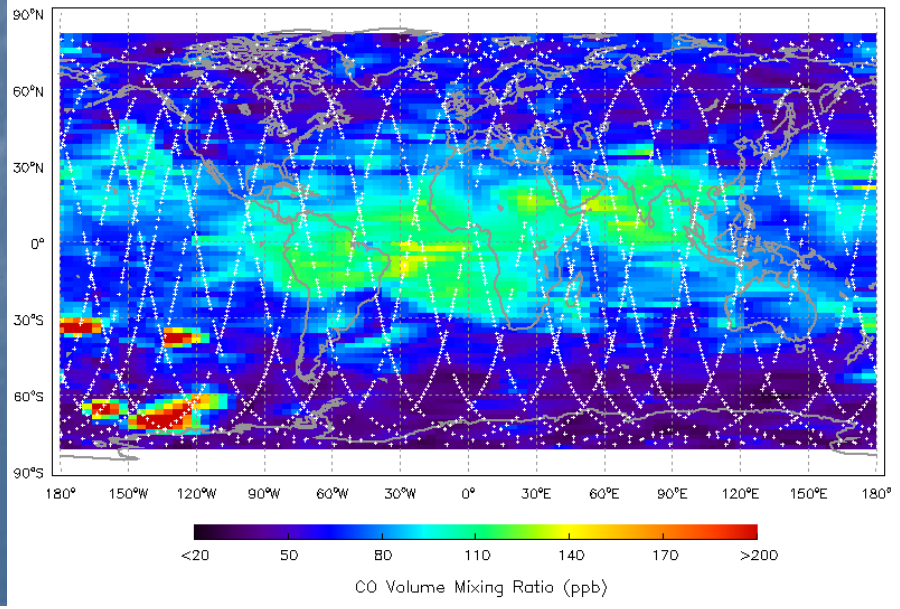
V003: Dec 16-17, 2006, P = 681.3 hPa



V002:Dec 16-17, 2006, P = 215.4 hPa

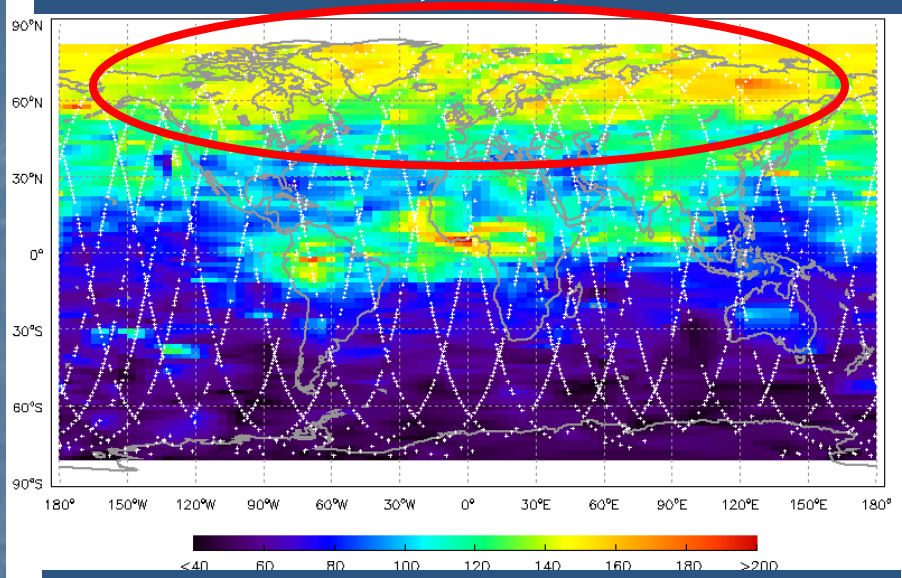


V003:Dec 16-17, 2006, P = 215.4 hPa

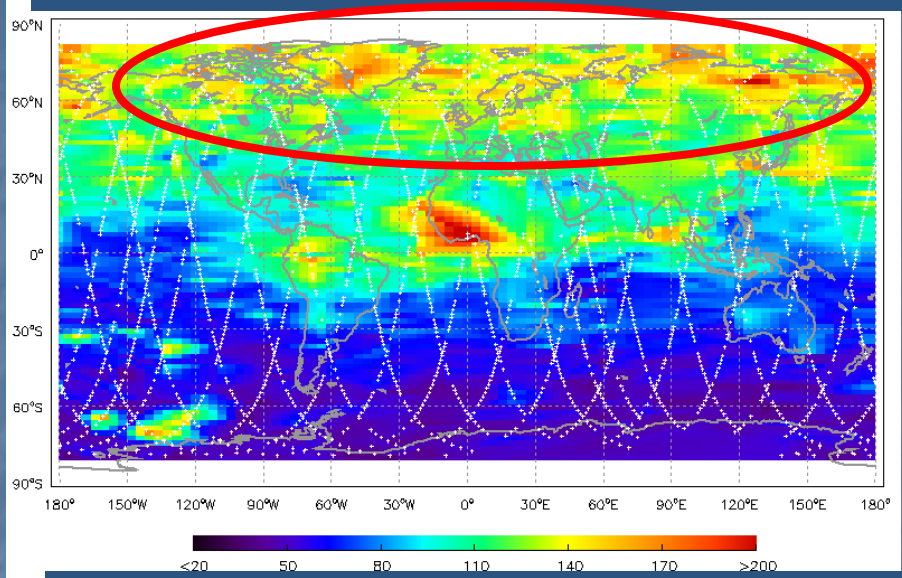


TES CO Global Surveys: V002 vs V003

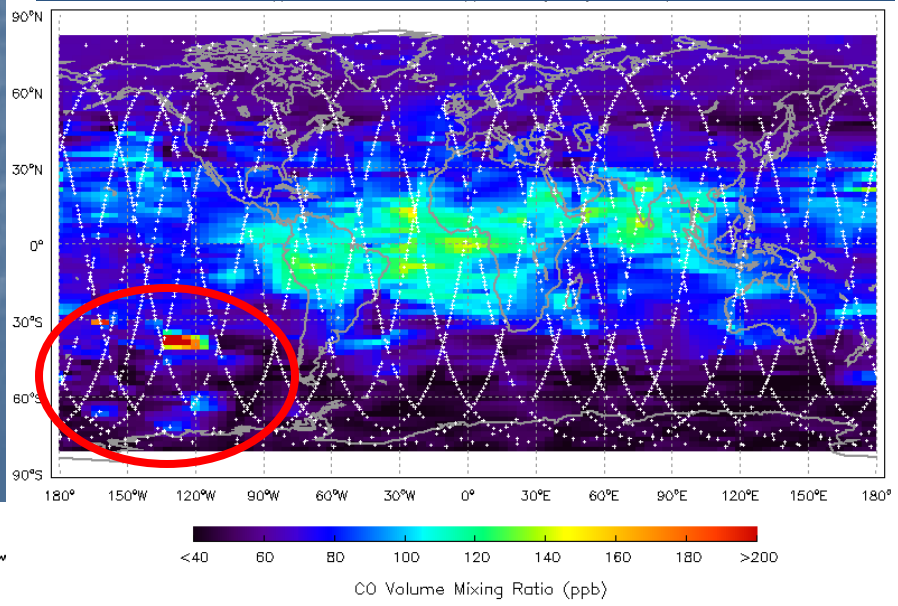
V002: Dec 16-17, 2006, P = 681.3 hPa



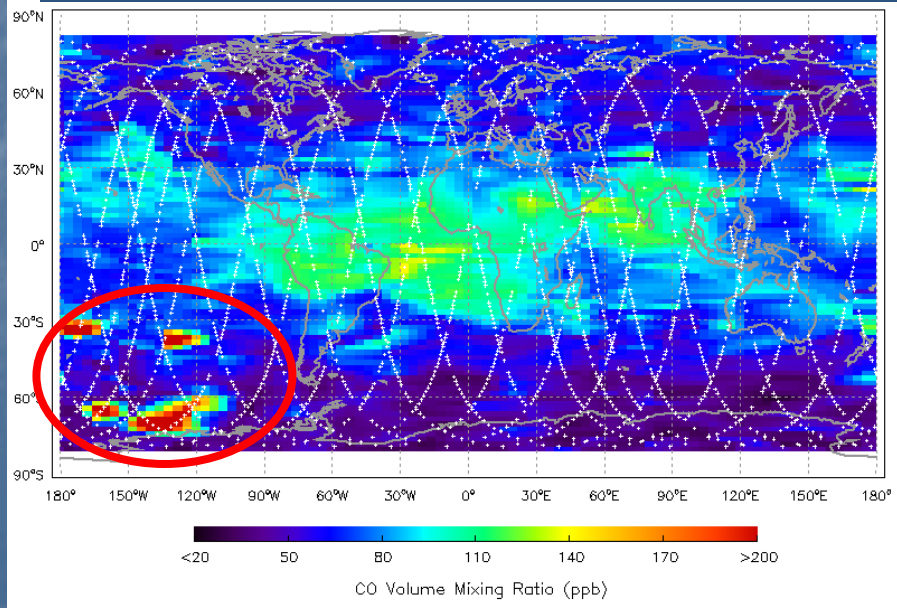
V003: Dec 16-17, 2006, P = 681.3 hPa



V002:Dec 16-17, 2006, P = 215.4 hPa

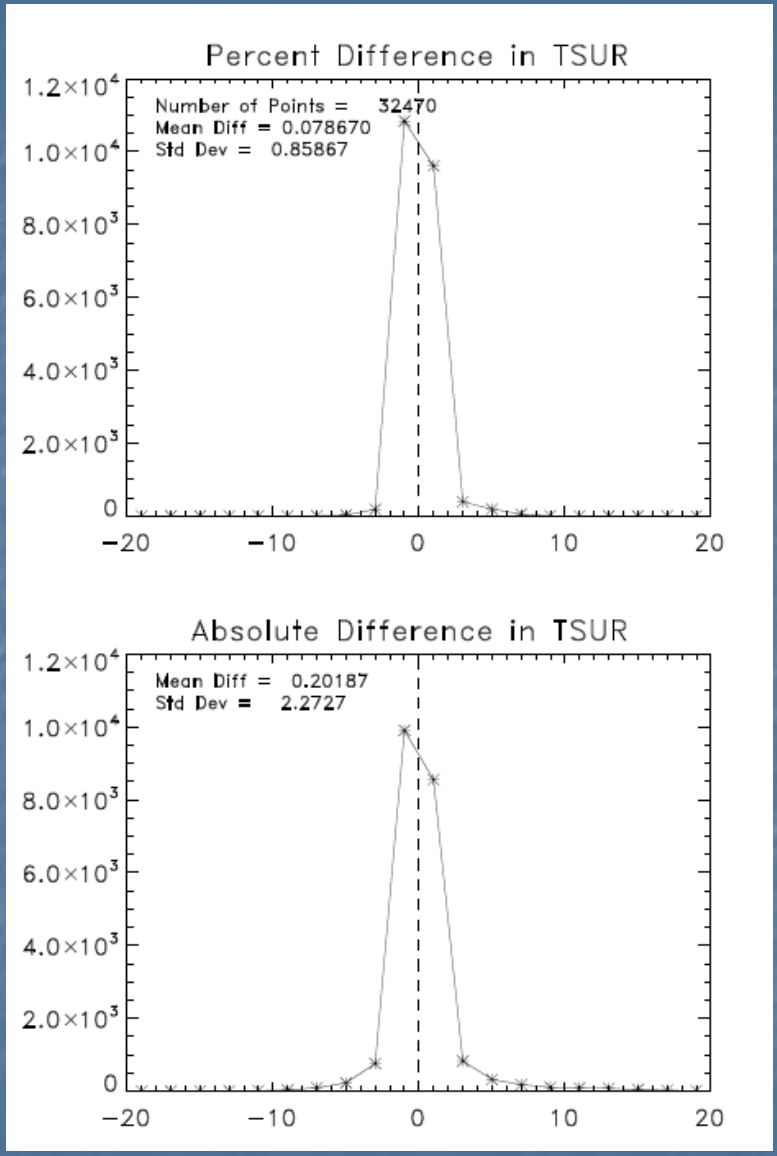


V003:Dec 16-17, 2006, P = 215.4 hPa



SST Temperature V03 – V02

- V003 TES data compared against V002
- 8 global surveys from 2005 and 2006
- Initial guess for V003 comes from GMAO GEOS-5
- Preliminary results (no cloud filtering)



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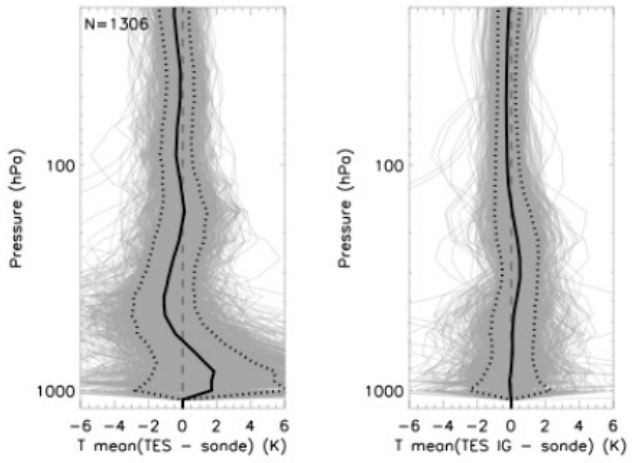
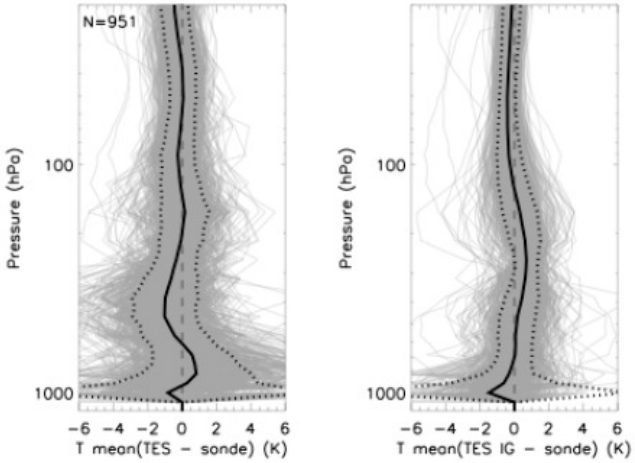
Nadir Temperature Seasonal Variation

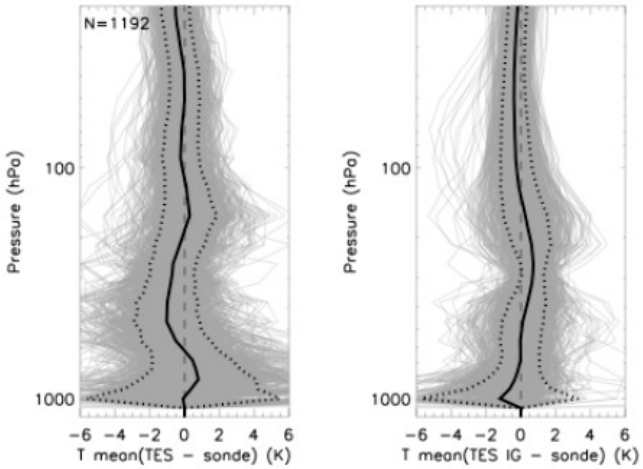
March



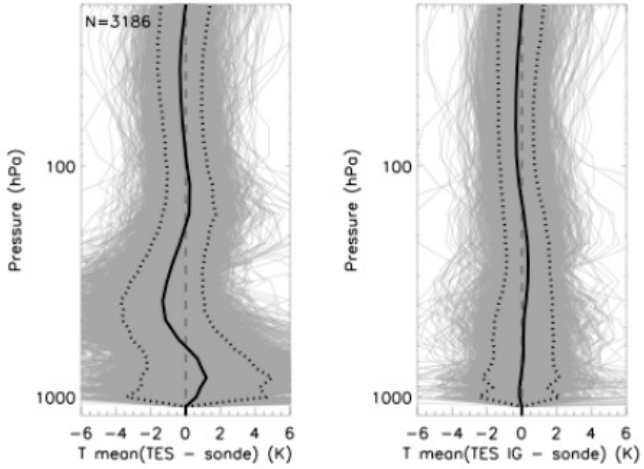
Sept



June

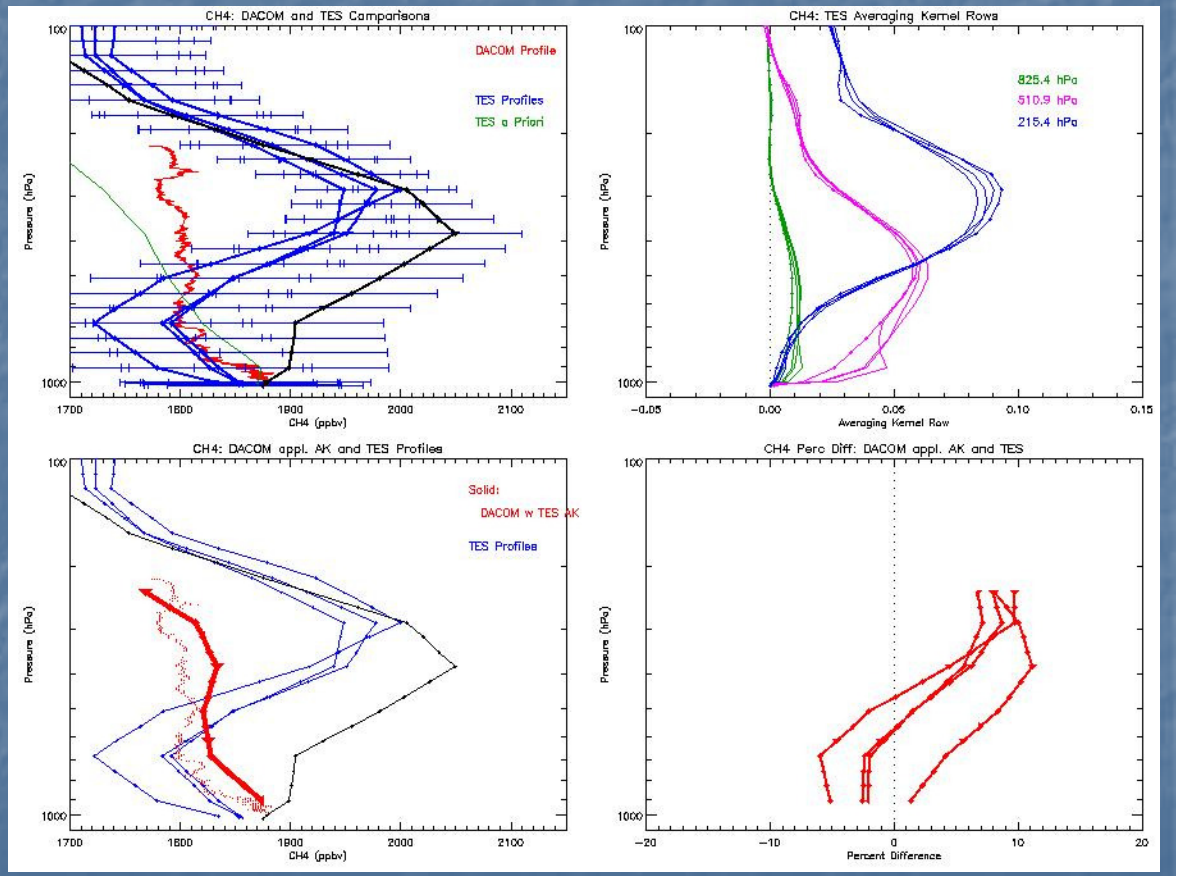


Dec



Methane Vertical Distribution

- Initial comparisons to DACOM (INTEX-B) and ground based FTIR (column)
- TES is ~5% high in column measurements
- Bias is seen between 150-500 hPa
- Limited validation data in free troposphere



B Fisher

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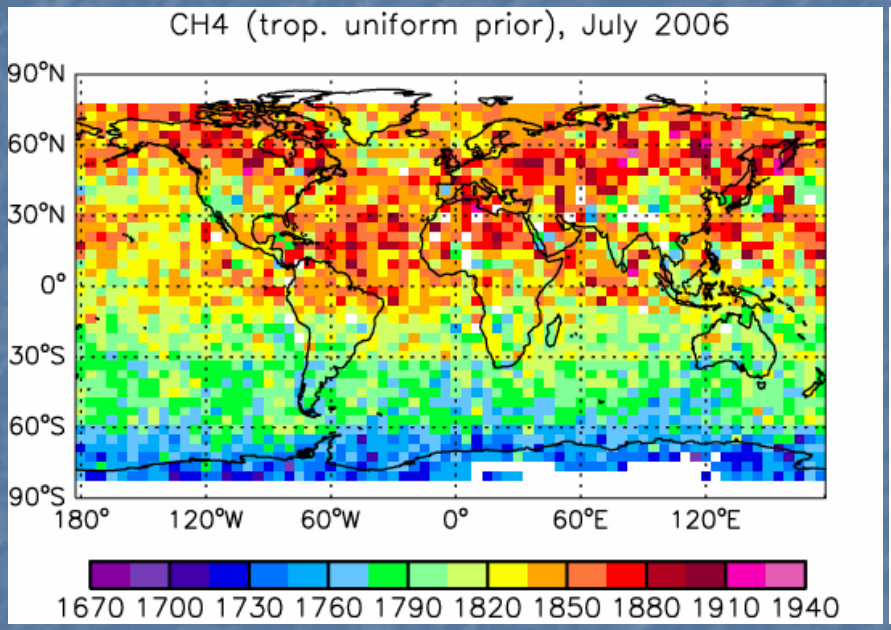
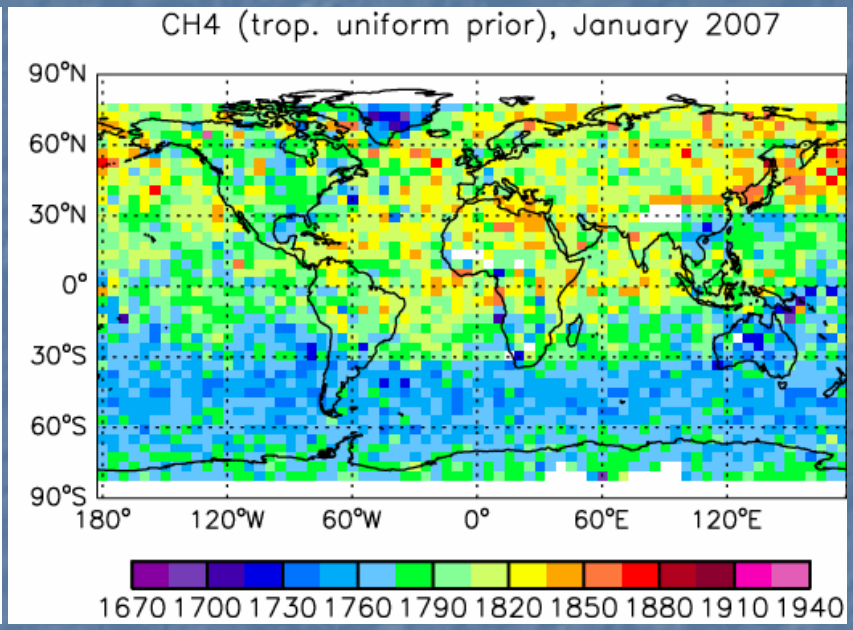
TES Global Methane Maps (681-247 hPa average) with uniform prior





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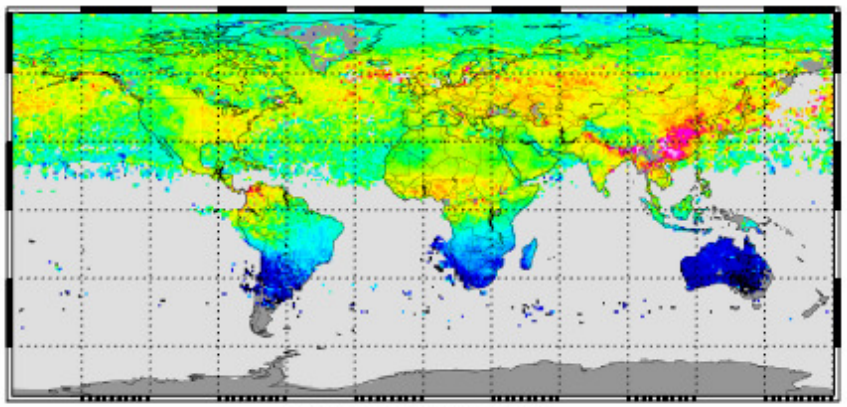
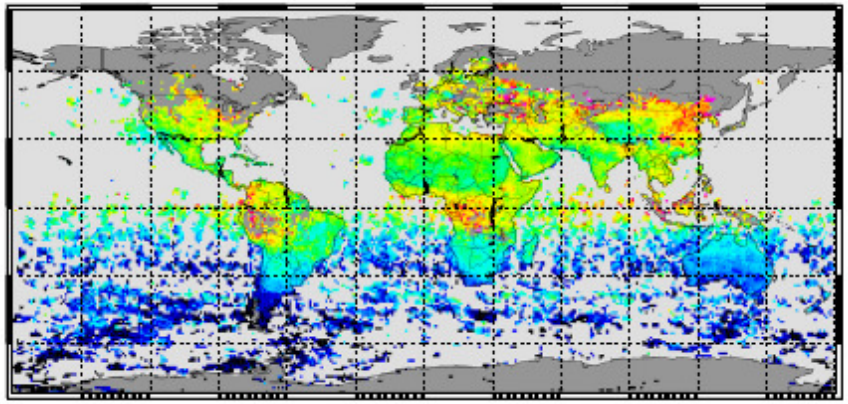
SCIAMACHY CH_4 Total Column Averaged VMRs



(E) JJA SCIAMACHY



(A) DJF SCIAMACHY

Frankenberg et al. (2006) JGR

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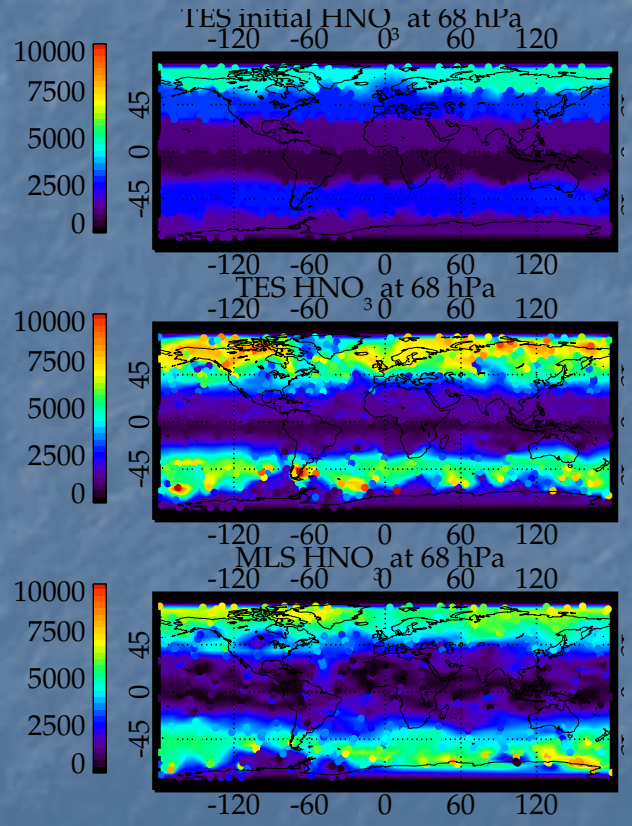
Nitric Acid

- Comparison with MLS and SAGA (DC-8) during INTEX-B
- TES cannot reach the troposphere due to limitations of clouds
- Comparison with MLS show similar spatial patterns in the stratosphere
- Comparisons with CIMS (WB-57) during CR-AVE show consistent spatial distributions (not shown)



S Kulawik

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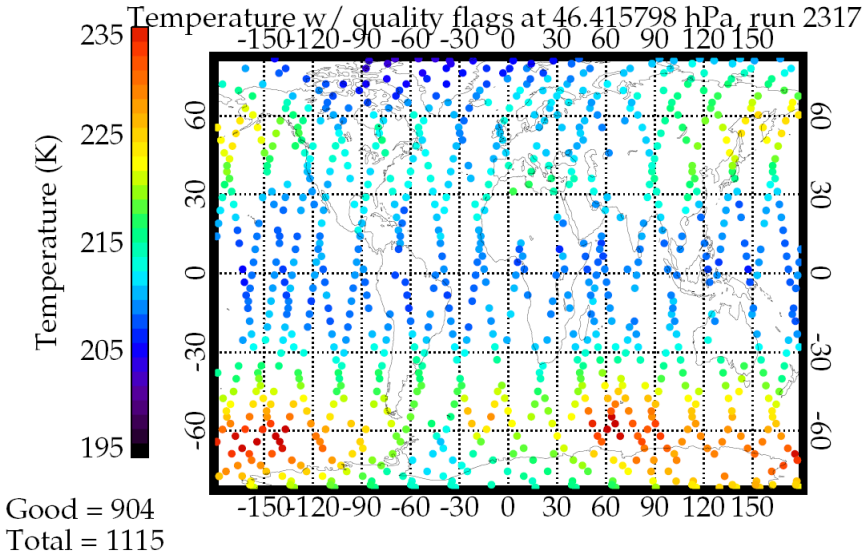
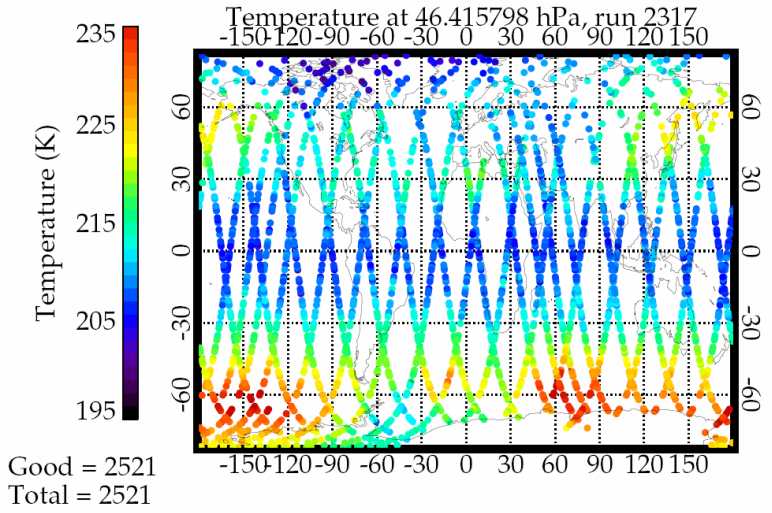
Temperature Comparisons





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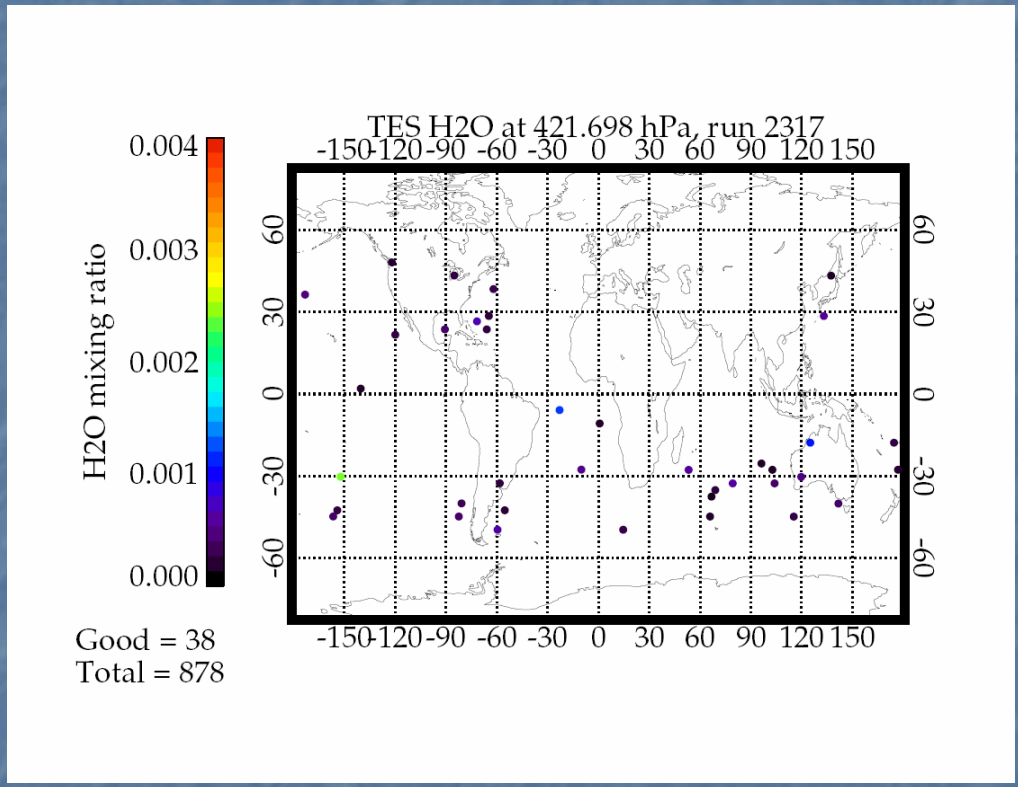
Limb Water

- Working to understand our limb water retrievals better
- Poor throughput



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2006 – A busy year for validation activities

- CR-AVE and Ticosonde (January 2006)
- ARM – Southern Great Plains Sondes (January – February)
- INTEX-B and MILAGRO (March – May)
- IONS 2006 (March – April, August)
- SAUNA (March – April)
- WAVES (July – August)
- Texas AQS (August – September)
- MOHAVE (October)

TES L2 Data Products Update – Version 2 (V002)

- TES Version 2 data has processed for all TES runs since launch
  - All processing goals were met for this version
- Significant improvements over previous version
  - L1B calibration improvement
  - L2 algorithm improvements
  - More extensive quality control information
- Version 2 includes HDO as a standard product
- Version 2 includes the first limb retrievals
  - Stratosphere only for this version
- Data available at the Langley Atmospheric Sciences Data Center (ASDC)
- Information on using TES data in the *TES L2 Data User's Guide* available at the Langley ASDC or the TES website

TES L2 Data Validation Overview

- TES Version 2 Nadir ozone data show improvements for comparisons to both ozonesondes and lidar (Talks by R. Nasser, N. Richards and H. Worden in the Total/Trop Ozone Validation subgroup)
- Carbon monoxide measurements taken after Dec 6, 2005 are significantly improved due to an optical bench warm up (Talk by M. Luo in the CO Validation subgroup).
- Validation results for nadir profiles of water, temperature and HDO look promising (Talks by R. Herman in the Water and Temperature Validation subgroups).
- Limb data for nitric acid, ozone and temperature are in the preliminary stages (Talk by S. Kulawik in the HNO3 Validation subgroup).
- A summary of the status of TES L2 validation will be provided in the TES L2 Validation Report (v2.0) available in October 2006.
- TES version 2 nadir data for ozone and carbon monoxide are validated and are fully appropriate for scientific studies by the atmospheric community.
- TES version 2 nadir water, temperature and HDO are provisionally validated and can be used (with caution) for scientific analysis.